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SOIL STERILIZATION

by

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Bayfordbury,
January 1955.

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INTRODUCTION

CHAPTER 1

WHY THIS BOOK WAS WRITTEN

SOIL sterilization is an old subject. So old that we might think there was nothing more to be said about it, certainly nothing new. But we should be wrong.

First, an embarrassing variety of research work has been published on the effect of sterilization on soil life, chemistry and physics; and an embarrassing difference of opinion confronts the author who attempts to make sense of it all. There are many questions still unanswered. Indeed, one is tempted to say that the only clear outcome of research is to emphasize the immense complexity of soil itself.

Secondly, it is only in the last year that the investigations of the John Innes Horticultural Institution and the National Institute of Agricultural Engineering have made it very clear that steam sterilization of glasshouse soils as practised in Britain (and doubtless, elsewhere) is often inefficient and unduly costly. In other words, there *is* new information: so new that this book could not have been written a year ago.

Thirdly, for the very reason that soil sterilization is an old practice, there is a large element of rule-of-thumb and make-do about it. Precision sterilizing has been as foreign to horticultural thought and practice as precision growing. And here a reminder may not be out of place. It was not until the many complexities in soil sterilization were first sorted out at the John Innes Horticultural Institution in 1939 that growers were able to make safe use of sterilized soil for seed and potting composts. Since then a generation has grown up that knows (perhaps) only the new rules, not the old perils. But the perils remain if the rules are not followed.

We can go further than all this. In modern horticulture clean soil is as indispensable for the health of glasshouse plants as clean water and clean food are indispensable for the health of people. Low seedling mortality, like low infant mortality, is the product of good hygiene and good nutrition. So also is rapid and robust growth, whether it be of men or plants. Soil sterilization is indispensable to modern practice, not only because it ensures clean soil but because it provides better nutrition; indeed, it is the basis of the best nutrition. Consequently, it is now true to say that the man who uses unsterilized soil for propagation is not only behind the times but substandard in his thinking and practice.

In writing this book I have had four objects in mind. First to present in non-technical language sufficient of the theoretical background to the subject to enable the reader to *carry out* sterilization with understanding and efficiency. My second object has been to describe fully the practice of soil sterilization, the apparatus employed and, where appropriate, its construction. These details range from the simplest requirements of the amateur—how to sterilize soil by the pint, to the most comprehensive requirements of the professional—how to sterilize soil by the acre. I have also discussed the treatment of soil after it has been sterilized. My third object has been to provide (1) a select list of publications for those who wish to delve deeper into the experimental and theoretical aspects of soil sterilization, and (2) figures and facts for day-to-day consultation in the practice of sterilizing, and for those who wish to make their own calculations on sundry matters.

Lastly, I have tried to be both selective and positive. Selective, by pointing out inefficient apparatus and methods, however cherished or long established. Positive, by giving numerical values wherever possible, and eschewing alternative recommendations when one is superior and will, therefore, suffice. It is my belief that readers—whether they be amateur gardeners, professional growers, advisory officers, students, or research workers—prefer an author to make clear recommendations rather than provide a comprehensive clutter of information culled from here, there and everywhere. To one who holds such a belief there remains one final, logical step: apparatus and methods require to be simplified and *standardized*, especially in commercial growing. Hence, the recommendations I have made in Appendix I are proposed as standards.

CHAPTER 2

WHAT STERILIZATION IS

WHAT is soil sterilization? To answer this question we must first ask another. What is soil? Unless we have at least a rough idea of what soil is, we can neither understand soil sterilization nor practise it intelligently and efficiently.

The average fertile soil comprises two distinct classes of materials or components; the non-living and the living.

In the non-living class are air and water; sand, silt and clay; mineral compounds such as chalk, nitrates, phosphates and potash; and organic matter comprised of the dead remains of plants and animals.

In the living class are micro-organisms such as bacteria and protozoa; fungi; weed seeds; and small animals such as nematodes, wireworms and grubs.

In the great majority of soils all of these non-living and living components will be found, though in varying proportions according to the type of soil and site. In particular, we should note that the living components occur in enormous numbers, for example, many tens of millions of micro-organisms per gram of fertile soil. Consequently, we should always think of soil as *living* soil, teeming with organisms and sensitive to everything which happens to it or is done to it.

Some of the organisms are useful, indeed essential, for soil fertility, e.g. the nitrate-forming bacteria. Other organisms are harmful to plant growth, e.g. bacterial and fungal diseases, eelworm and grub pests, seeds which give rise to weeds that compete for the cultivated plants' food and water. Though not strictly entitled to be called 'organisms,' we may include here those viruses which persist in plant remains in the soil.

Out-of-doors, where the soil is exposed to the weather and crop rotation is practised, the useful and harmful micro-organisms (excluding eelworms) achieve a certain balance and the soil remains fertile. But in glasshouses the weather cannot ameliorate the soil and intensive cropping, often with little or no rotation, soon brings on micro-organism unbalance. The result is the soil becomes 'sick' and crop yields seriously fall off. In addition to this micro-organism unbalance, pests and diseases specific to the crop may accumulate and still further depress yields.

In the simplest terms, soil sterilization consists in getting rid of the organisms harmful to plant growth—or, at least, in reducing their numbers to a point where they are no longer of consequence—without permanently eliminating or disturbing the balance of those organisms essential for fertility.

It will be clear from this definition that the word 'sterilization' is a misnomer. Soil which was truly sterile would, as ordinarily used by growers, be lifeless and useless. Partial sterilization, pasteurization, disinfestation, are other descriptions which have been suggested from time to time. As we shall see later, none is accurate, none is comprehensive. And as no satisfactory term has been found we might as well go on using the term 'sterilization,' if only because it is so well established in the horticultural vocabulary.

Before leaving this question of what sterilization is, there is another definition on which stress must be laid. Some people may say, 'I don't sterilize my soil but I get excellent results, so why bother about sterilization?' It is true that an excellent result may be had from the use of *un*sterilized soil.* But true excellence lies in the ability to achieve good results not once, or now and again, but time after time, at will. To excel, one must eliminate risks and uncertainty and be able to guarantee results. From long acquaintance, both in experience and experiment, of raising a great variety of plants, I have no hesitation in saying that soil sterilization may also be defined as the best *insurance* against the risk of soil-borne pests and diseases; a risk which not even the most skilled and knowledgeable plantsman can afford to ignore; a risk which is inherent to all growing; a risk which, though unpredictable, can be avoided—thanks to soil sterilization.

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* It should be noted, however, that short of a critical experiment, this is no proof that still better results would not have been obtained from the same soil had it been sterilized.

PART I

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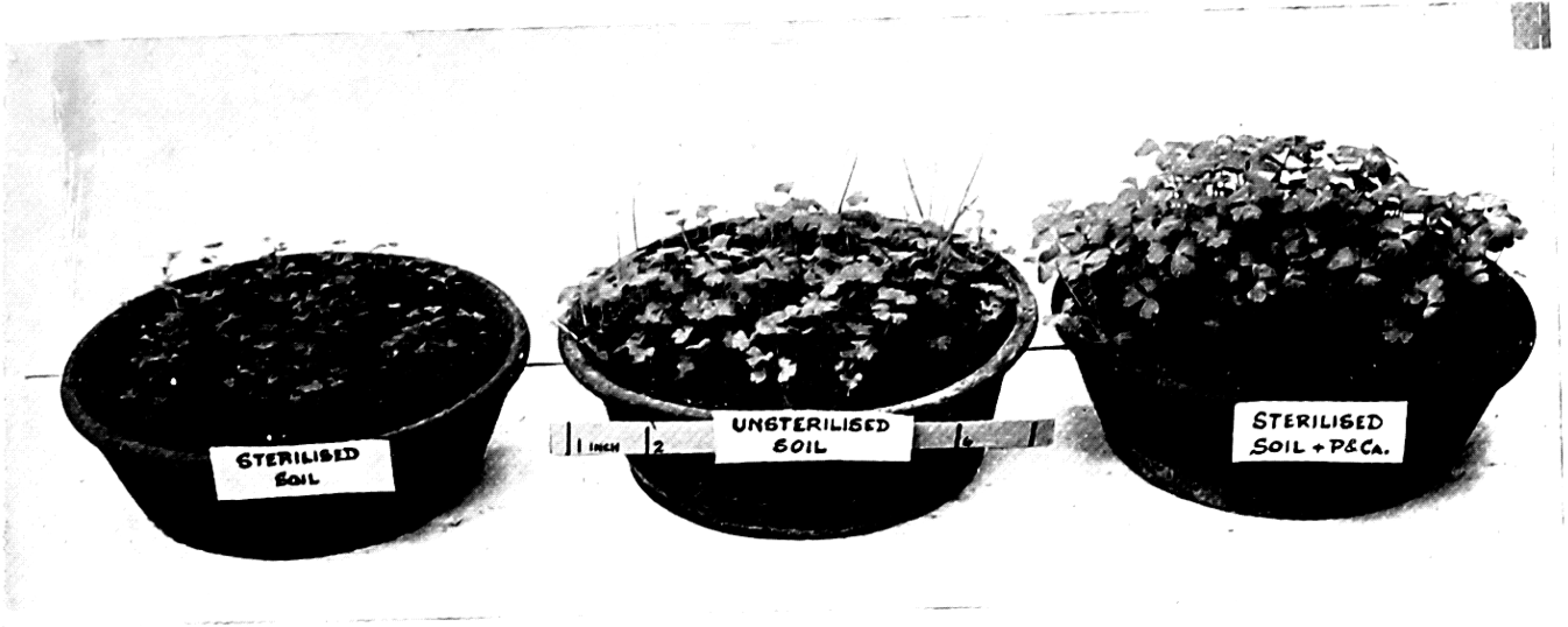

FIG. 1.—Showing retardation of seedling growth in sterilized soil (*celery*)

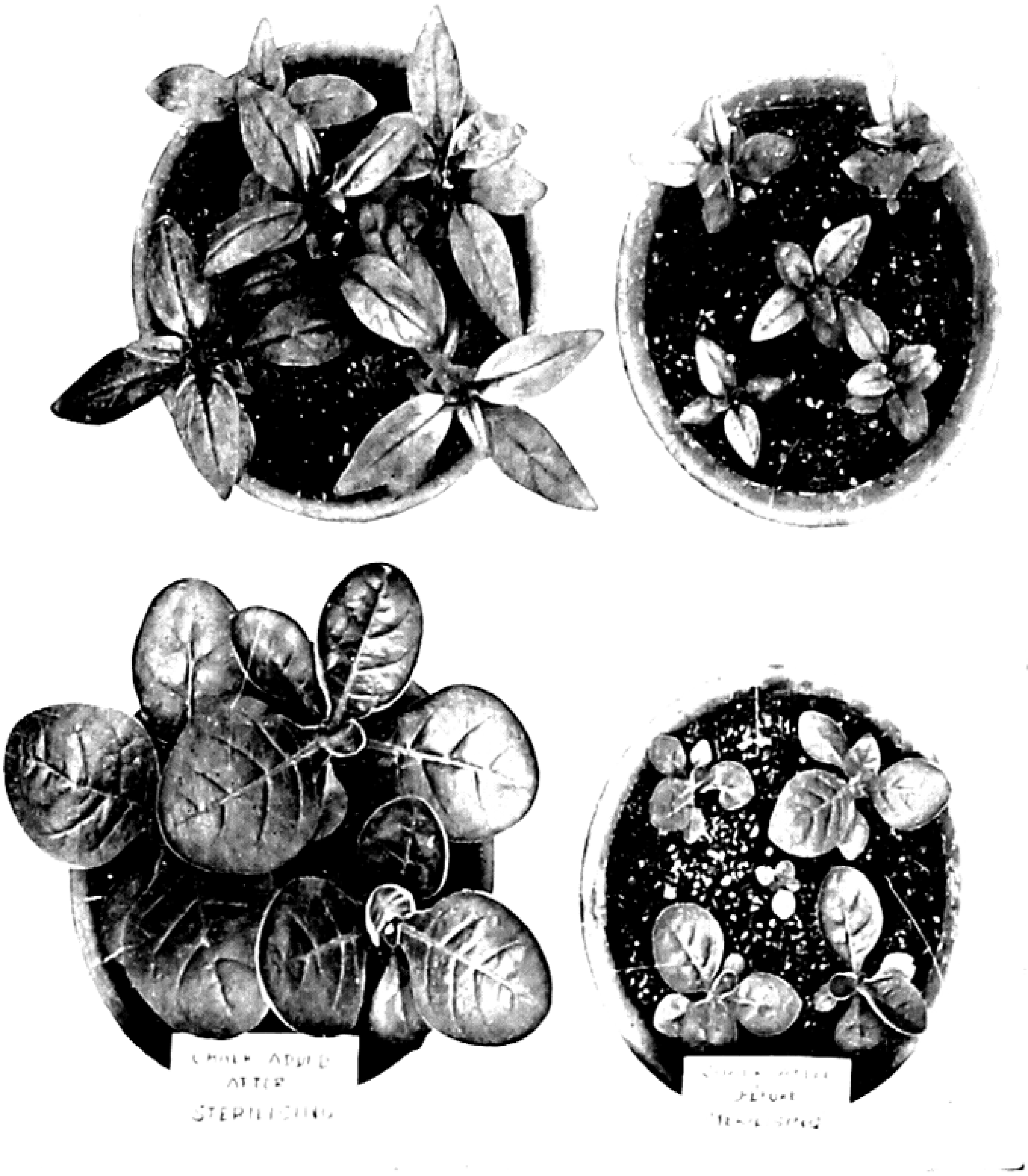

FIG. 2.—*Left*. Chalk added to the compost after the soil has been sterilized. *Right*. Chalk added before sterilization (*Antirrhinum and tobacco*)

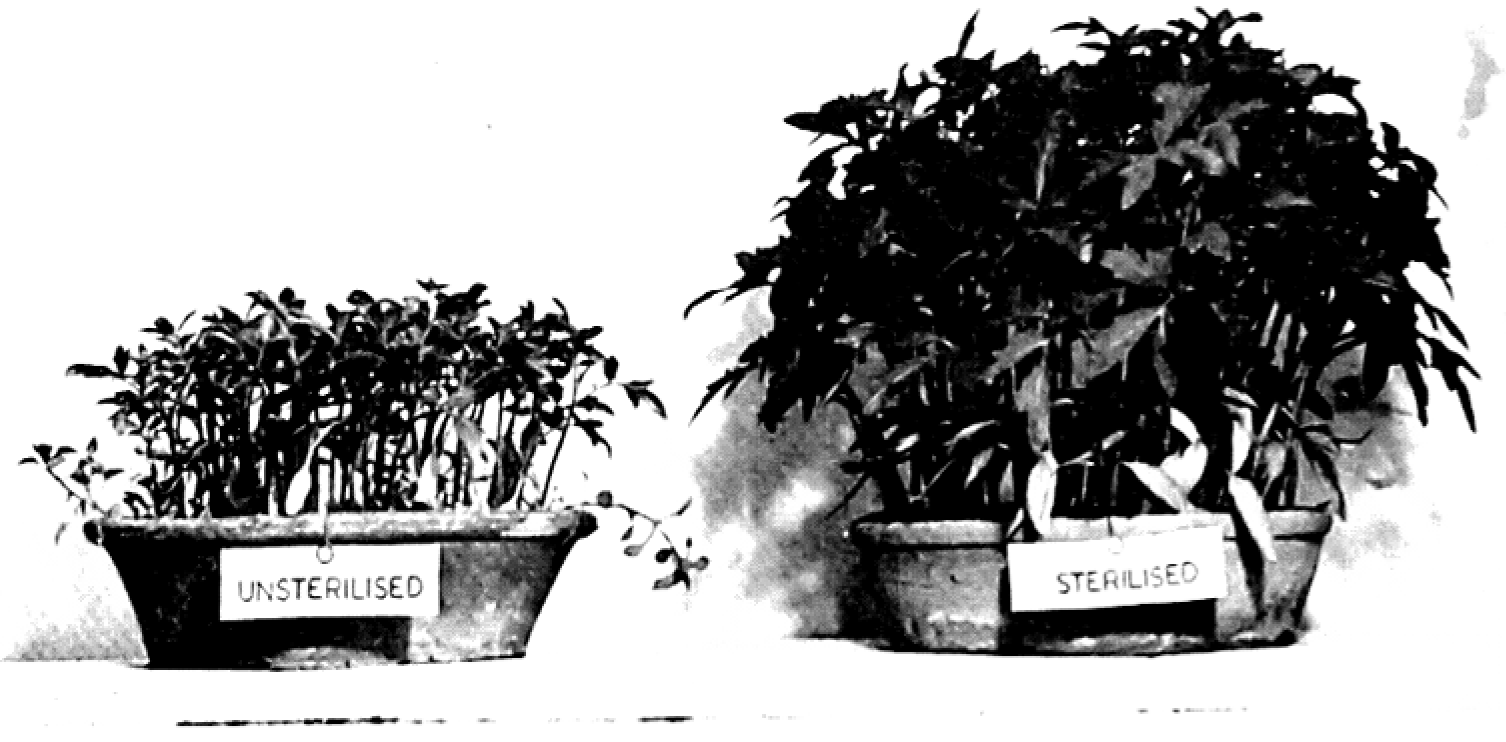

FIG. 3.—The soil in these pans is a thin, 'hungry,' blackish one from the South Downs. It carried no pests or diseases that would attack tomato seedlings. Hence, the luxuriant growth seen in the steam-sterilized soil on the right is due to increase in the amounts of plant nutrients. Sterilizing has enriched the soil.

CHAPTER 3

WHAT HEAT DOES: TO SOIL LIFE

WHAT sterilization does to soil depends on two things. The nature and history of the soil; the precise method of sterilization. We will learn something about the first of these as we go along. The second we will look at right away.

The temperature of outdoor soil varies with the succession of night and day and of the seasons. In Britain, surface temperatures commonly range from 15° F. (− 9° C.) in winter to 115° F. (46° C.) in summer. Similarly, in glasshouses, though the extremes of soil temperature are not so great, wide variations occur.

These variations affect soil structure and soil life much more than is realized, soil life especially being sensitive to change of temperature. Nevertheless, for our purposes, we may say that up to temperatures in the region of 115° F. the changes induced in soil are moderate in degree and balance and do not seriously affect plant growth.

As soil temperature is raised higher and higher beyond 115° F. the situation becomes markedly different. Outstanding physical and chemical changes occur while the effect on some forms of soil life may be catastrophic. At 212° F. (100° C.) these changes may be such as to impair the soil for subsequent use as a satisfactory medium for seed germination and seedling growth of many species. At 260° F. (127° C.) all life in the soil is killed and it is then truly sterile.

So far, we have spoken of temperature only. Time comes into the picture too. First, it takes time to heat soil. Secondly, once the sterilizing temperature is reached it generally has to be maintained for a time. Thirdly, it takes time for the hot soil to cool. The degree of soil moisture also plays a part, moist heat being more effective in sterilization than dry heat.

Temperature and time are all important in the heat sterilization of soil. Many experiments in many countries have shown that a given temperature maintained for a given time is lethal for a given organism harmful to plant growth. This temperature is called the *thermal death point*. It will be noticed that this phrase puts all the emphasis on the temperature, as if ignoring the element of time. However, it is convenient to retain the term 'thermal death point' and to note at what temperatures various soil-borne organisms may safely be reckoned to be killed when exposed to moist heat for 10 minutes.

Table 1

Approximate thermal death point °F.	Approximate thermal death point °C.	Organism
130	54	weeds, earthworms, eelworms
160	71	weed seeds, wireworms, non-spore-forming fungi, protozoa, nitrifying and other bacteria
180	82	carnation wilt disease, nearly all viruses
200	93	tomato mosaic virus

As will be seen from the table, the great majority of pests and diseases are killed when a temperature of 160° F. is maintained for 10 minutes (1, 2).* But the figures are based mainly on experimental conditions and do not allow, for instance, for the slow penetration of heat into lumps of soil. Under practical conditions there must be a safety margin. The author, therefore, has long recommended 180° F. for 10 minutes as giving a reasonable margin of safety and long experience has substantiated this view.

Using steam under pressure the soil temperature is bound to rise to 212° F. But the figure of 180° F is applicable and important when the heating process is (1) slow, as in very low rate steam injection (page 116), or (2) regulated, as in electric sterilizers (page 125) and steam-air sterilizing (page 120).

So much for the thermal death point of the harmful organisms we wish to be rid of. However, there are other organisms present in soil, invisible to the eye, concerned in varying degrees with plant growth. Two of these micro-organisms deserve special mention, not merely because they are of great importance to plant growth, but also because their reaction to heat is an excellent example of the way the balance of soil life is temporarily altered by sterilization, generally with important consequences to the plant.

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* Throughout the text, the numbers in brackets refer to the publications listed on page 164.

As we all know, when animals and plants die they begin to rot or decompose. This decomposition is carried out by fungi and bacteria which attack the complex structure of the dead animal or plant and break it down, stage by stage, into simpler substances until, finally, there remain only the simplest compounds such as carbon-dioxide and water from which the animal or plant was originally built up. Normally, organic matter is found in the soil in all stages of decomposition at one and the same time. In the course of decomposition certain chemical substances which at the beginning are so tightly bound up in complex compounds, such as cell and muscle tissue, as to be insoluble in water, eventually become soluble and are then readily absorbed by plant roots. In this way, insoluble organic materials are changed by fungi and bacteria into soluble *salts* (nutrients) available to plants.

Now to return to the two types of organisms that illustrate the manner in which the balance of soil life is disturbed by heat sterilization. The first of these organisms are the many species of ammonifying bacteria that attack decomposing organic matter at a certain stage to produce *ammonium compounds* containing nitrogen. Secondly, there are the nitrifying bacteria, *Nitrosomonas* which oxidize ammonuim salts to *nitrite*, and *Nitrobacter* which oxidize nitrite to the still simpler *nitrate*. It is in nitrate form that nitrogen is most readily absorbed by plants which, indeed, normally take in most of their nitrogen as nitrate. Therefore, we are bound to be interested in the fate of the nitrifying bacteria when soil is heat sterilized.

What is their fate? They are killed. This, however, is not the calamity one might suppose it to be, for most plants appear to be able to absorb nitrogen in the form of ammonium compounds. What, then, does heat do to the ammonifying bacteria? Fortunately they survive sterilization in fair numbers. Unlike the nitrifying bacteria which exist as thin-walled cells very susceptible to heat, the ammonifying bacteria produce thick-wall cells, or spores, which can survive 212° F.

The consequence of this selective action of heat on the ammonifying and nitrifying bacteria will be obvious. Heat sterilized soil, for some weeks after sterilization, generally contains much more ammonium nitrogen, e.g. 5 to 10 times, than before sterilization (3, 4). In other words, nitrate production ceases with the killing of the nitrifying bacteria, whereas ammonium production not only goes on but may increase greatly under certain conditions, e.g. when the soil to be sterilized is wet, also when sterilized soil cools slowly (5). In one to two months, however, nitrate production begins again owing to spores of nitrifying bacteria, some of which are always present in the air, falling on to the soil and multiplying, so that the nitrate-ammonium balance becomes more normal. This period of unbalance need not be detrimental to plants grown in heat-sterilized soil but, as we shall see later, unless certain simple precautions are taken when the soil is sterilized, growth, especially seedling growth, *may* be retarded or 'checked' and in extreme cases serious damage caused.

SUMMARY

1. Soil pests and diseases can be destroyed by heat with ease and efficiency. In practice, the safe minimum sterilizing temperature is 180° F. maintained for 10 minutes.

2. In addition to killing harmful organisms, heat also disturbs the balance of useful organisms with a consequent alteration in the kind and amount of nitrogenous (and other) compounds available to the plant. This alteration in the nitrogen supply may be of great or small adverse consequence to seedling growth, depending on a variety of conditions, especially the *method* of heat sterilization.

3. In general, the heating of soils with high organic content, high moisture content and high pH, is likely to lead to a marked increase, first in ammonium and later in nitrate content, especially when such soils are cooled slowly, e.g. *in situ* in glasshouses, or in a large heap after bin sterilization (page 66).

CHAPTER 4

WHAT HEAT DOES: TO SOIL CHEMICALS

WE saw in Chapter 1 that soil consists of two main classes of materials, the living and the non-living. We have also seen that the non-living materials can be conveniently divided into two further classes:

1. Organic compounds comprising the decomposing remains of animals and plants and such bulky manures as the grower may have applied to the soil, and
2. Inorganic compounds derived from the minerals that form the bulk of the soil and such fertilizers as have been applied.

Heat sterilization affects both organic and inorganic compounds. On the organic side the amount of water-soluble matter is increased to an extent depending on the state of the organic material. Thus, chemically stable material does not react appreciably to heat, e.g. unrotted leaves, stems and roots at one end of the scale, or, at the other end, completely humified material, such as brown moss peat. But unstable, actively decomposing material readily reacts to heat. Exactly what happens is far from clear but it seems that decomposition is hastened and, under certain conditions, some of the products formed are harmful (toxic) to plants. Ammonia and/or water soluble organic compounds in toxic amount have long been suspected and sometimes claimed to be the cause of retardation of plant, and especially seedling, growth (Fig. 1). There is evidence that the application of large amounts of calcium carbonate to certain types of loams, principally those rich in natural organic matter, increases the sterilizing check (Fig. 2).

On both the organic and inorganic sides, the effect of heat sterilization is to increase the amount of soluble phosphate, potash, manganese, zinc, iron, copper, boron, etc., more of some of these compounds than others. And, correspondingly, higher concentrations of these elements are found in plants grown in sterilized soil (6).

In consequence of the above situation, moderate heating may benefit the plant by increasing the availability of nutrients (Fig. 3). The soil is made 'richer.' But over-heating, or prolonged heating, may produce an excess of one or more soluble compounds, e.g. salts, and raise the osmotic pressure* of the soil water. The soil is 'poisoned.' It has been shown that retardation and damage to seedling growth extend progressively beyond temperatures which kill all bacteria. On the other hand, no sterilizing check is found if clay is heated to red heat. The inference is that the harmful effects are associated with the organic content of the soil. Thus, the 'poisoning' of soil through over-sterilization may arise from the direct action of heat on organic compounds, as well as through its effect on bacterial activity. For all of the above reasons, a degree of nutrient unbalance commonly results from the heating of soil.

Now, unsterilized soil may have a soluble salt concentration nearly high enough to be detrimental to seedling growth. It may be argued, therefore, that sterilization of such soil may increase the soluble salt concentration to the point where the root system is damaged or the crop markedly disturbed, according to the severity of the conditions. The soils most likely to have a high soluble salt content are those found in established gardens, nurseries or glasshouses, where fertilizers, manures and lime have been used too freely for some years. As a matter of fact, cases are known where sterilization of such soils has led to depressed crop yields, a reminder that sterilization, so beneficial in the majority of cases, is no substitute for good husbandry. If a grower is compelled to sterilize a glasshouse soil known to have a high soluble salt content, he should recognize the risk involved and take suitable precautions by seeking advice, re-considering his system of husbandry, flooding the soil, etc.

It should be specially noted that soil which is to be sterilized for seed and potting composts is better obtained from agricultural rather than horticultural land, the rate of application of manures and fertilizers, etc., in agriculture being, of course, much lower than in horticulture. But a word of precaution is necessary here. Emerging clearly from the welter of experimental results is the fact that a large and possibly harmful increase in soluble manganese (6, 7) often follows the heating of acid, virgin (i.e. agricultural) loams. Hence, it is better to avoid acid loams (pH 4·0–5·0) for the making of seed and potting composts; and to raise the pH of slightly acid loams to about 6·3 by adding ground chalk or limestone to the loam when it is stacked (page 72).

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* The higher the osmotic pressure, the less water is taken up by the roots, consequently the more likely that the plant will suffer damage.

At this point, it may be well to make clear that it is not yet possible to predict just how a particular soil will behave on sterilizing (Fig. 4); nor whether the risk of producing excess salts, etc., is large or small. What is beyond doubt is that, in the past, before the main factors were sorted out, many growers got into trouble with seed germination and seedling growth. It is equally beyond doubt that *no troubles at all need arise* if the issues discussed in this and the last chapter are appreciated and the correct techniques of sterilization, described later, are adopted. Sterilization by heat can be perfectly safe and perfectly satisfactory.

SUMMARY

1. The amount of each of a number of water soluble chemical compounds is increased by heat sterilization and there is increased absorption of these compounds by plants grown in sterilized soil.
2. Some compounds are made soluble in larger amount than others, hence nutrient unbalance commonly ensues. The degree of chemical unbalance ranges from very small to very large, depending on the nature of the soil and the amount of heat applied.
3. The degree of unbalance is unpredictable, but it can be minimized by observing simple precautions.

CHAPTER 5

WHAT HEAT DOES: TO SOIL STRUCTURE

THE word structure refers to the size and characteristics of the porous 'crumbs' of soil built up naturally from the much smaller mineral particles of clay, silt, sand and humus. In these crumbs, the humus acts as a cement to stick together the mineral particles.

Soils poor in humus content are poor in structure, e.g. sandy or clay soils. On the other hand, the top inches of clay soil under an old pasture will have an excellent structure resulting from the high humus content and dense root system associated with grass. Frost will temporarily produce structure in a ploughed or dug clay soil but rain or trampling will rapidly destroy it.

These examples have been quoted to show that although crumb structure occurs naturally under certain conditions, it can also be built up, or broken down, or prevented from forming, by artificial means, i.e. by good or bad husbandry.

How does soil sterilization fit into this picture? Firstly, heat directly affects crumb structure. Although all too little critical research has been done on the subject, there is wide agreement, based on practical experience, that heat sterilization improves crumb structure, renders the soil more friable and thus produces better aeration.

Secondly, this improvement in structure is a temporary one. Over a matter of months the structure gradually reverts to its original condition. Consequently, the addition of organic matter to soil that is repeatedly sterilized (e.g. glasshouse soils) is accepted as an important factor in building up and maintaining crumb structure. Heat sterilization accelerates the decomposition of organic matter, which must be regularly replaced in suitable amount and kind.

Heat sterilization produces other changes in soil behaviour of importance to growers. Better crumb structure permits excess water to drain away more readily, especially in the heavier soils. It is also stated that heat sterilization reduces 'the water holding capacity of soils,' though presumably this is a transient effect.

SUMMARY

Very little research has been done on the effect of heat sterilization on the structure of soils. It is, however, generally accepted that crumb structure (tilth), aeration and drainage are all improved. In the case of glasshouse soils, regular additions of suitable organic matter are recommended as a necessary complement to sterilization.

CHAPTER 6

WHAT STERILIZATION DOES: TO PLANT GROWTH

FOR convenience we have considered separately what heat does to soil life, chemicals and structure but in practice the results of heat sterilization must be regarded as a whole. Some effects are beneficial to plant growth, some adverse, depending on the nature and condition of the soil, the degree and duration of heating and the species and age of the plant. It is the balance of good and bad effects which must be the final consideration.

Seedlings

In general, the harmful results derive, directly or indirectly, from an excess of certain soluble compounds. What constitutes a harmful excess depends on the species of plant concerned. Thus, the growth and development of tomato and cucumber seedlings may be retarded but not sufficiently to attract the attention of the grower. Nevertheless, this check to growth may increase his production costs. On the other hand, germination and growth of *Antirrhinum*,* *Verbena* and *Primula malacoides* are easily disturbed (Fig. 5) and the correct sterilization technique must be followed if good results are to be achieved with these species. The situation is epitomized in the pun:

> *The smaller the check to the seedling,*
> *the larger the cheque from the crop.*

Just here we may remind ourselves of the apposite comment '. . . the precise cause of [seedling] retardation is not yet ascertained, . . . but it probably arises from the excess of ammonia and other decomposition products which are useful enough for older plants but form too aldermanic a diet for the seedling' (8).* A statement made 45 years ago but still thoroughly up-to-date.

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* *Antirrhinum* seedlings are sufficiently sensitive as to make good test subjects for assessing the efficiency of soil sterilization.

To come back to the central issue, what matters is that the balance of helpful over harmful results should be so large as to obscure entirely the occurrence of the latter, *for occur they nearly always do* even under the best conditions. I have put this phrase in italics because very few gardeners and growers realize that although their plants and crops may appear to flourish, they could often be better still (rate of growth, development and yield) if the arrangements for, and carrying out of, soil sterilization were given the little extra thought and care that pay so handsomely.

Let me leave no doubt about the ease and efficiency with which everyone may practise soil sterilization for seedlings. *Heat sterilization carried out as recommended in this book may be strictly described as 'fool-proof,' i.e. not even the novice need go astray.*

Older plants

The older the plant (or portion of a plant, e.g. cutting), the less likely is it to react to nutrient unbalance or to toxic effects. Indeed, the problem, typically, is no longer one of retarded growth but of excess vigour. This is best seen when, following autumn or winter sterilization of glasshouse soil, tomatoes are planted in February or early March. The immediate danger is that the plants will grow rankly, become soft and leafy and fail to 'set' their fruits. Given correct husbandry, the increased vigour ultimately leads to increased productivity; and crop yields in old glasshouse soils may rise in spectacular fashion, say from 40 tons per acre to 50 or even 60.

The most notable feature of increased plant vigour following soil sterilization is the size and healthiness of the root system (Fig. 6). A number of theories have been advanced to account for this and vigour generally. Probably, the destruction of harmful organisms, especially those directly attacking the roots, together with an improved balance and supply of soluble nutrients, account for the greater part of the increased vigour and productiveness.

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* But whereas Russell and Pethybridge also said 'no remedy can be suggested,' today we have the remedy, though we still await the explanation.

SUMMARY

Incorrect soil sterilization results in:

1. The growth of seedlings being weak and retarded.
2. The growth of older plants being too vigorous. Correct soil sterilization brings under control, at one and the same time, the causes of retardation and excess vigour and the best is had of two worlds—the world of the propagating house and the world of the plant house.

CHAPTER 7

STEAM: ITS PROPERTIES

SO long as we don't go into too many technicalities we shall find it an advantage to know something about those properties of steam relevant to soil sterilization. What follows, therefore, is a simplified account.

Steam Energy

Suppose we raise the temperature of 1 lb. of water from freezing point (32° F.) to boiling point (212° F.), maintaining a constant atmospheric pressure (14·7 lb. per sq. in. absolute or 0 lb. gauge) throughout, then we have raised the temperature of the water by 180° F. and, in doing so, used heat amounting to 180 British Thermal Units. In other words, the B.Th.U. (or Btu), as defined, is the amount of heat necessary to raise the temperature of 1 lb. of water by 1° F.

Suppose now that we wish to turn this 1 lb. of boiling water into steam. To do this, we must go on adding heat to the water. This extra heat has no effect on the temperature of the water which remains steady at 212° F. What the extra heat does is to change the water into steam by evaporation. At atmospheric pressure, the amount of heat required to change 1 lb. water at 212° F. into steam is about 970 Btu.

Thus, the making of steam involves two stages. In the first stage, 180 Btu of *sensible* heat, as it is called, are necessary to raise the temperature of the water from freezing to boiling. In the second stage, 970 Btu of *latent* heat are necessary to change all the water into steam.* And, in all, 1,150 Btu *total* heat will have been used. The steam will occupy, at atmospheric pressure, 1,600 times the volume of water from which it was made.

Now, just as we can add heat to a substance, so, too, we can allow the substance to give it up, i.e. to cool. Thus, if 1 lb. of steam at atmospheric pressure is changed back into water, 970 Btu of latent heat are given up. This is the only heat which is available for soil sterilization and for practical calculations we can round off the figure of 970 to 1,000 Btu.

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* These are not, of course, different kinds of heat. The words 'sensible' and 'latent' are merely convenient terms to distinguish two different phases of the heating process.

Super-heated Steam

The heating process need not stop short at turning water into steam. The steam, in the absence of water, can be heated to temperatures above the appropriate boiling point. This is called *super-heating*. If the temperature of the steam is raised, say, 10° F. above boiling point, then the steam is said to have 10° F. of super-heat. The influence of super-heat on soil sterilization is small and can be neglected.

Wet Steam

Another property of steam, broadly speaking, is that it may be wet or dry. Steam at the relevant boiling point is said to be *saturated*. If it is pure steam, with no droplets of unevaporated water present, then it is called *dry saturated* steam.

Now when, in soil sterilization, steam is fed from a boiler into a steam main, some of it condenses and this water may be swept along with the steam. Also, drops of water or foam may be carried out of the boiler with the steam. Such a mixture of true steam vapour and liquid droplets is called *wet* steam and the wetness is expressed as percentage weight. Thus, steam which is 5 per cent wet* contains 5 per cent of water in the liquid state. From one cause or another, the steam used in soil sterilization is usually wet, e.g. at least 5 per cent with high-pressure† boilers. It is desirable that this water should not be blown into the soil along with the steam. The water can easily be separated from the steam and drained harmlessly away (page 83).

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* Often referred to as 95 per cent dryness, etc.

† In horticulture, and especially in soil sterilization, the term 'high-pressure boiler' has for many years been used to denote a boiler that works at a pressure of 60 to 120 lb./sq. in. The boiler maker, however, calls this a medium-pressure boiler. To avoid confusion, I have followed horticultural usage with respect to the term 'high-pressure boiler' (cf. soil 'sterilization,' page 14). Further, in this book, 'low-pressure boiler' means a boiler that works at any pressure up to about 25 lb./sq. in.

Steam Pressure

So far we have been discussing steam at atmospheric pressure. In soil sterilization, however, steam is very often produced under pressure in a boiler and this steam has a slightly greater total heat (up to 3 per cent) than when it is at atmospheric pressure (a fact which has little bearing on the efficient sterilizing of soil). The higher the pressure, the more the sensible and total heat and the less the latent heat. This can be seen from Table 2 which gives some of the properties of saturated steam.

Table 2

THE HEAT ENERGY IN STEAM

Pressure lb. sq. in. (gauge)	Temperature °F.	Heat Btu/lb.			Approximate volume of steam to water	Heat available for sterilizing (= total minus sensible heat)
		Sensible	Latent	Total		
0	212	180	971	1151	1605	971
10	239	208	953	1161	976	981
15	250	218	946	1184	818	984
20	259	228	940	1168	702	988
25	267	236	935	1170	620	990
30	274	243	930	1173	550	993
40	288	256	920	1177	453	997
60	307	277	905	1182	334	1002
80	324	295	893	1187	264	1007
100	338	309	882	1191	219	1011
120	350	322	872	1193	186	1013

Of what value is this information to the man who seeks efficiency in the practice of soil sterilization? Very little. Steam tables are of importance for the solution of many problems concerned with heat. But in efficient soil sterilization, whatever the pressure in the boiler or the sensible, latent and total heat values, by the time the steam is delivered to the soil it is close to atmospheric pressure, actually about ½ lb./sq. in. (psi), and will have the characteristics of steam at atmospheric pressure. Small differences in super-heat and steam wetness can be ignored. Table 2 does show, however, that by far the greater part of the total heat in steam is latent heat. By and large, therefore, there is nothing for us to bother about in these aspects of steam pressure.

There is, however, another aspect of the matter which should bother us a good deal and that is the widespread misunderstanding about the part that steam pressure plays in soil sterilization. For something like fifty years there has been a strong tradition in British commercial horticulture that rapid sterilization is achieved only when steam is forced into the soil at 'high' pressure. Actually, high *boiler* pressure itself, 60–120 psi, has been thought to ensure rapid and efficient steaming. There can be few ideas in horticulture which have been so persistent, so wrong and so costly.

What are the *facts* we must grasp in order to understand clearly the part played by steam pressure in soil sterilization, especially of glasshouse soils. There are only two and they are very simple.

The first is that there is a limit to the rate at which soil can absorb steam. If this limit is exceeded, the surplus steam passes through the soil, escapes into the air and is wasted. It is patently absurd and wasteful to attempt to force steam into a soil faster than it can be used with efficiency. *The rate should not exceed about* 18 *lb. steam per sq. ft. of soil surface per hour* (9). This does not apply to soil sterilization in bins (page 66).

The second fact concerns the size (diameter) of the steam main.* Clearly, the main also must be able to pass steam at the required rate of 18 lb./sq. ft./hour. How big must it be to do this? Common sense tells us that no amount of pressure could force steam in adequate quantity through a very small pipe. Clearly, too, the sheer physical difficulty of hauling large metal pipes about puts a limit on their size in the upward direction. In practice, the sizes of steel mains most often used are 1¼ in. and 1½ in.: a compromise between the pipe that is too small to pass enough steam and one that is too large to move about conveniently. Recently, light alloy mains have become available and diameters up to 3 in. are now quite convenient.

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* Including all the pipes, e.g. rubber hoses, connecting the boiler to the steaming pipes.

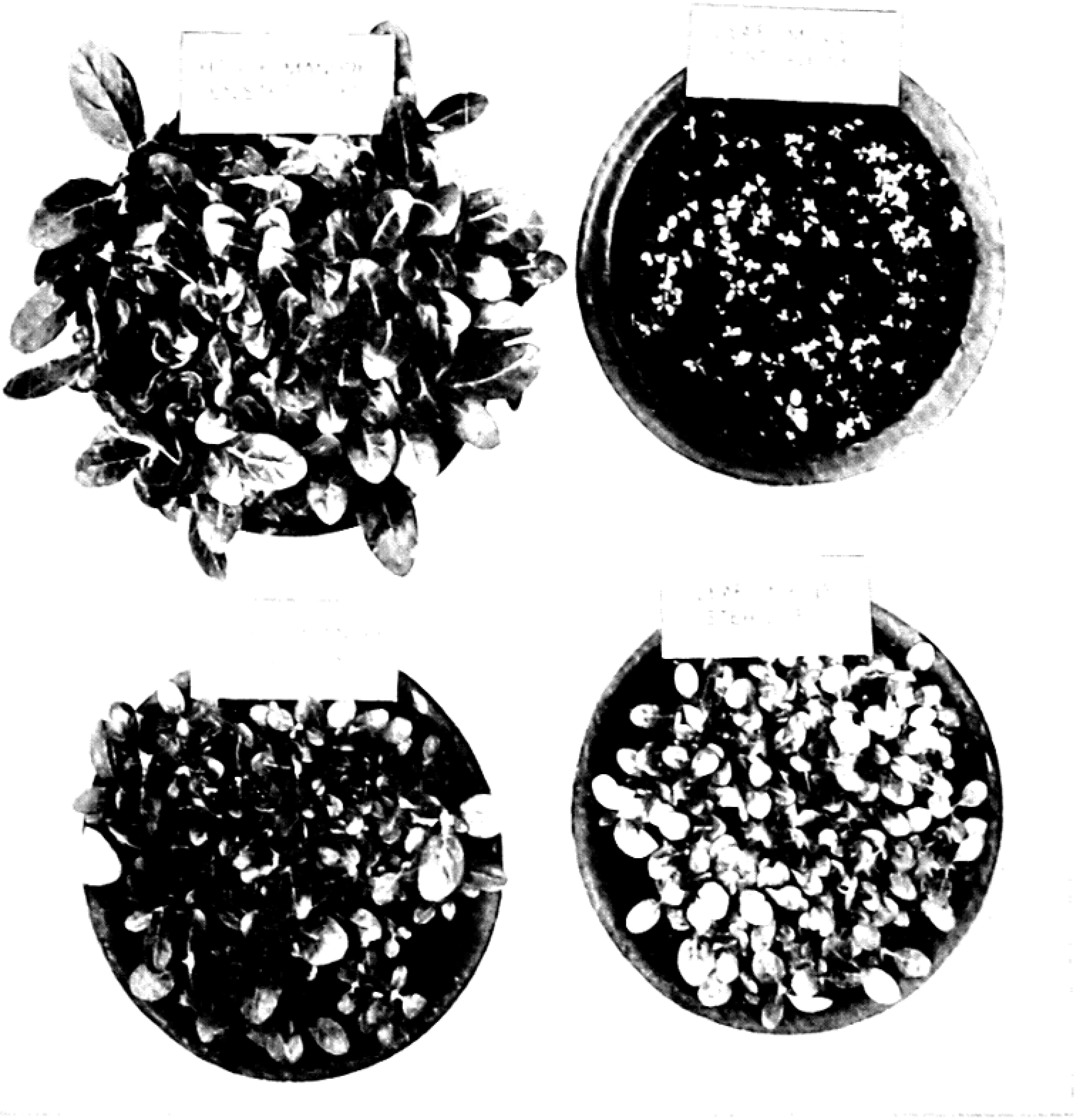


FIG. 4.—Illustrating the unpredictable effects of heat sterilization on the growth of *Nicotiana*.

Left. Well-rotted horse manure. *Right*. Well-rotted leaf-mould.
Top. Unsterilized. *Bottom*. Steam sterilized.

The result from sterilizing manure is probably due to an excess of soluble material which has retarded growth. The result from sterilizing leaf-mould is probably due to a moderate increase in plant nutrients (originally deficient in amount) which has accelerated growth. Compare Fig. 1.

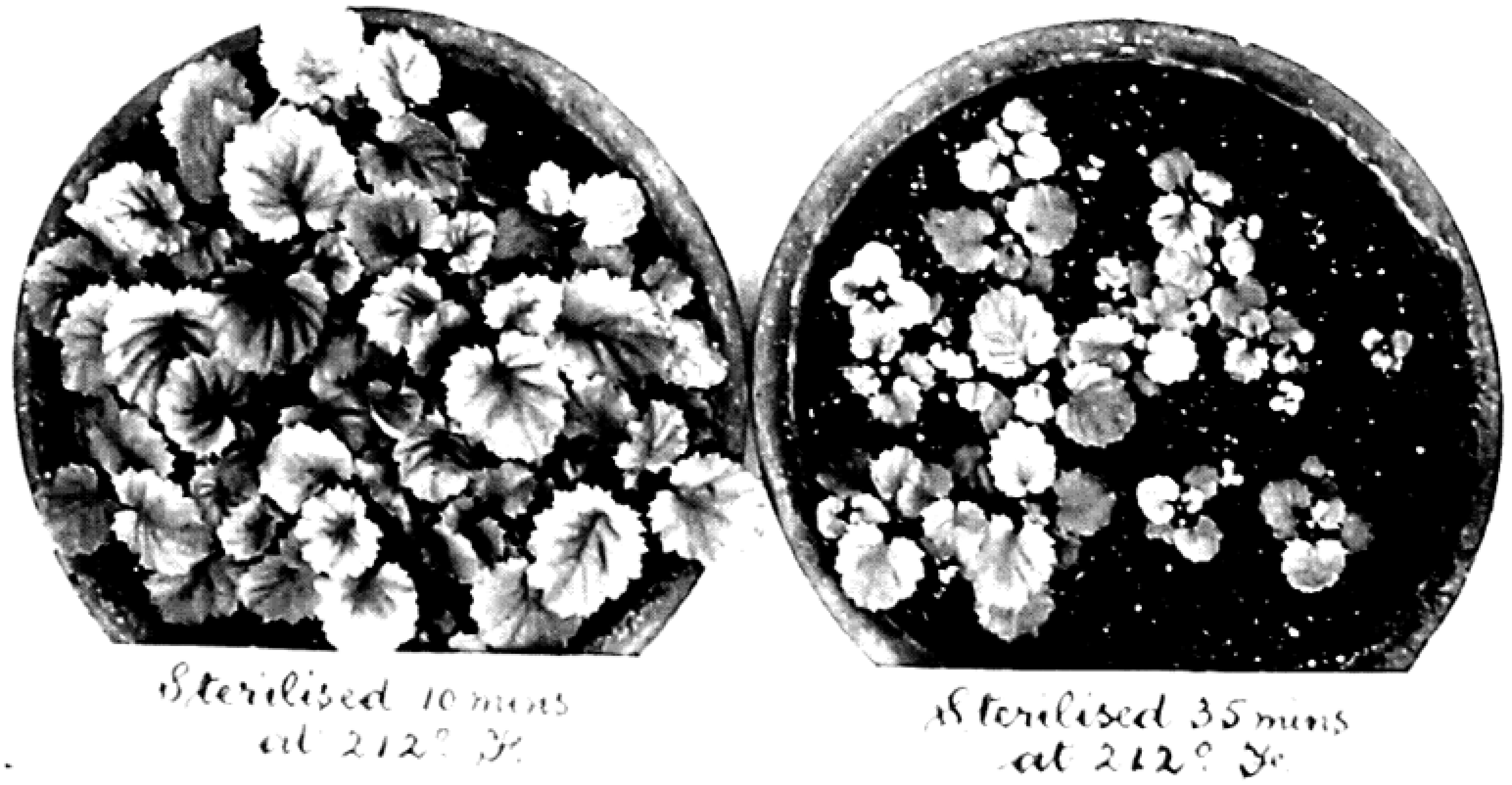


FIG. 5.—Showing ill-effects of prolonged heating of soil (*Primula malacoides*)

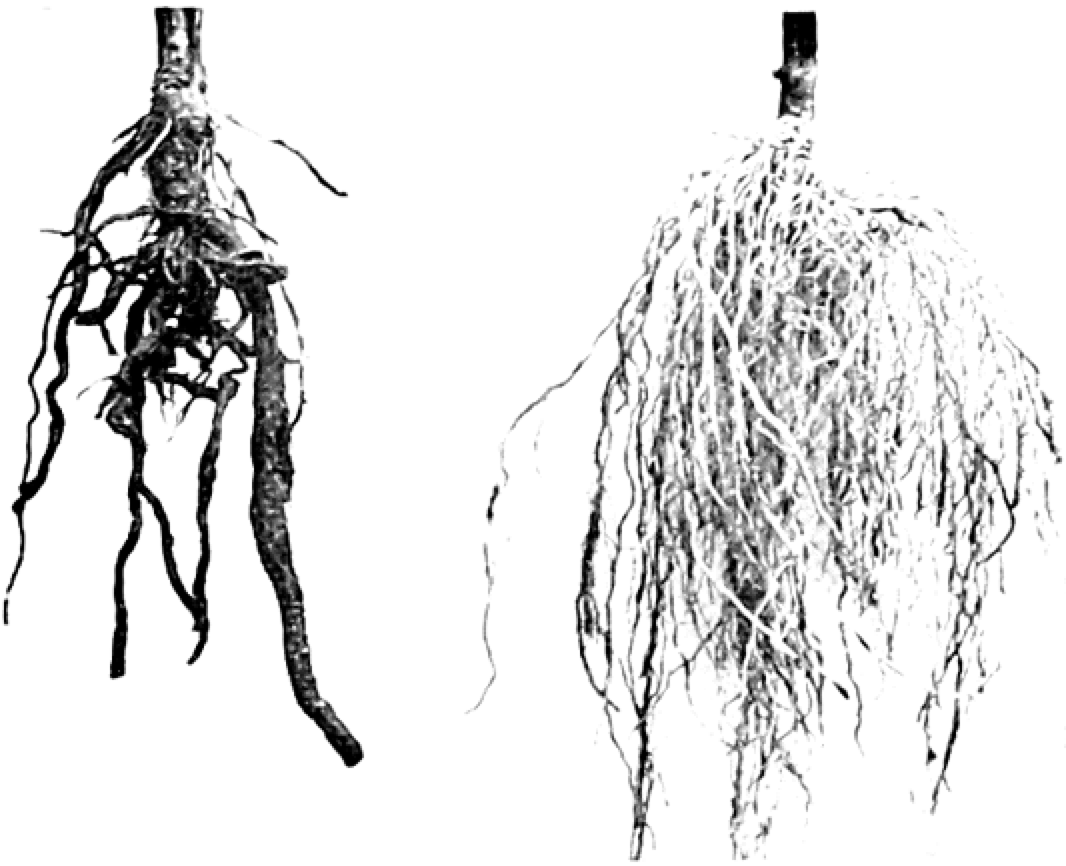
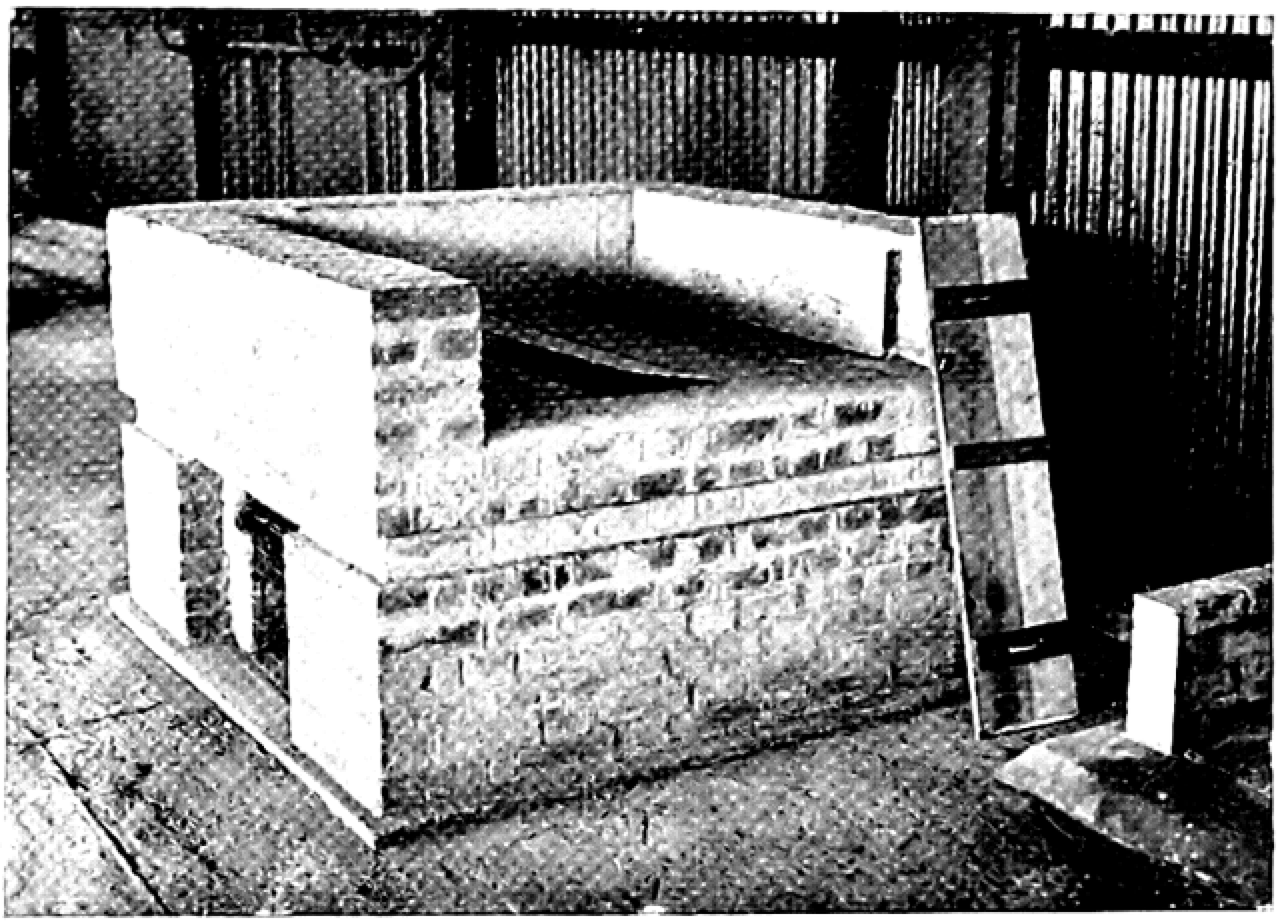


FIG. 6.—Typical root systems of *Tomato*.

Left. Plant grown in unsterilized soil: main roots brown and corky, side shoots few.
Right. Plant grown in steamed soil: main roots healthy, side shoots many.

FIG. 9.—The John Innes Low-Rate Sterilizer.



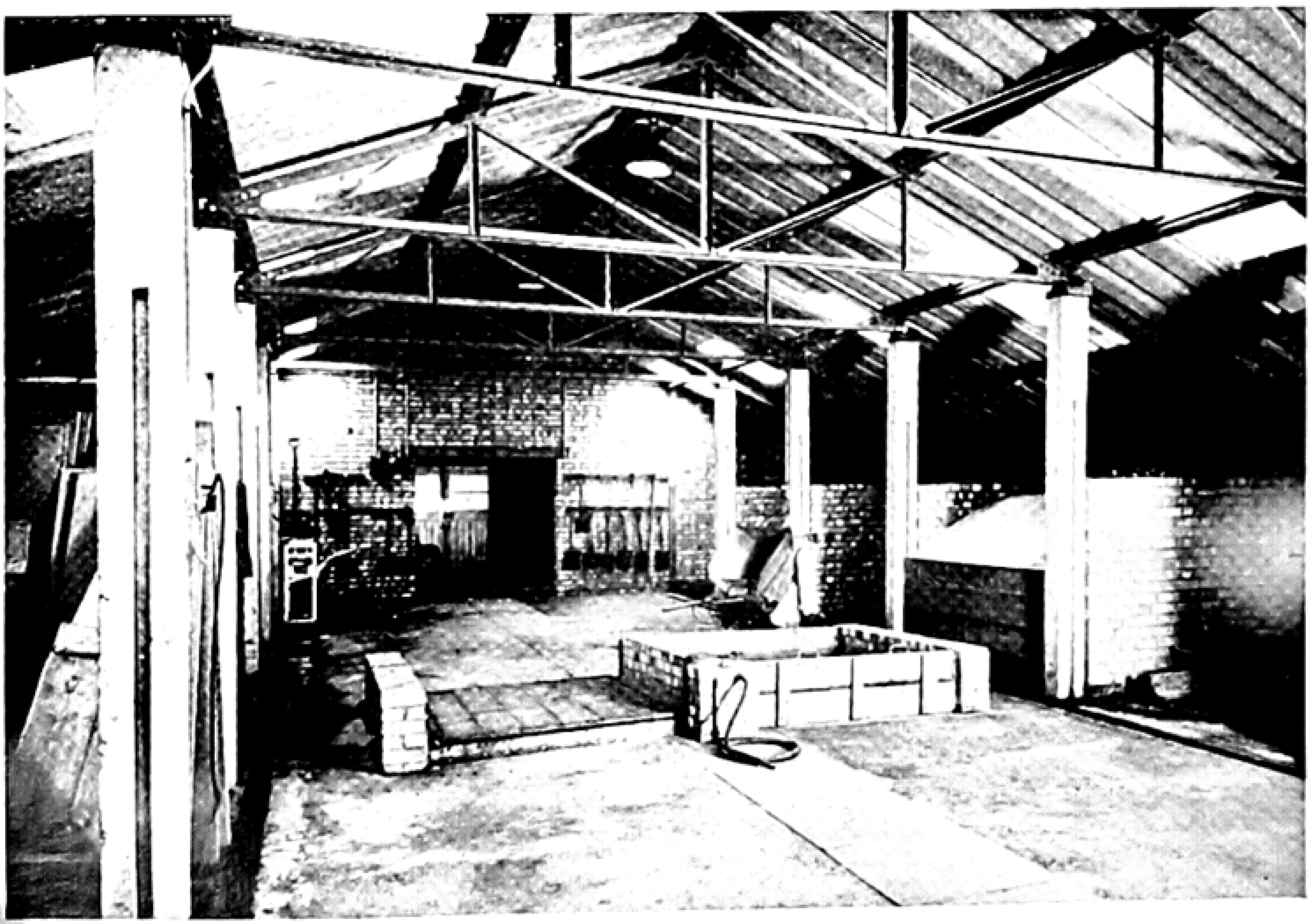


FIG. 16.—Sterilizing and mixing shed at Bayfordbury. Two 1 cubic yard sterilizing bins in foreground. Soil-shredding and mixing machine in right background. Note hose (middle wall of bins) used for sterilizing the shredding machine. This is done by 'spraying' it with steam after it has been used for shredding unsterilized soil, i.e. *before* it is used for mixing compost. See also Fig. 19.

So far so good. Let us re-state these facts, putting the emphasis where it properly lies.

1. The *quantity* of steam required for efficient steaming is about 18 lb. steam/sq. ft. soil/hour.
2. There must be enough pressure at the boiler to overcome the frictional resistance of a given size and length of pipe, so that the full *quantity* of steam reaches the soil.

Notice that it is *quantity* of steam that matters; pressure is incidental. The quantity of steam passed will depend on main size and length and boiler pressure. In theory, if we know the main size then we should be able to specify the boiler pressure to push the required quantity of steam through a given length of pipe. Conversely, if we know the boiler pressure then, similarly, we should be able to specify the size and length of main.

Full-scale experiments just concluded at the John Innes Horticultural Institution (10) give the first reliable answers. Boiler output was 1,200 lb. steam/hour. The equipment used at the end of the main consisted of 15 ft. of 2 in. steam hose leading to a header and two 6 ft. lengths of 2 in. steam hose leading to two sub-headers. Four 5½ ft. Hoddesdon pipes were fed from each sub-header (equivalent to the four 7 ft. Hoddesdon pipes to each sub-header required for a 1,500 lb. boiler, page 93). Table 3 (overleaf) shows the approximate pressures required at the beginning of the main to give a rate of steam flow of 1,200 lb./hour.

The implication of the figures in Table 3 is as follows (all four cases rest on the use of 2 in. steam hoses at the end of the mains):

1. With low-pressure boilers used in the range 5 to 15 psi, a 3 in. main is adequate for any length required in normal glasshouse practice.
2. With low-pressure boilers used in the range 15 to 25 psi, a 2 in. main is adequate.
3. With high-pressure boilers used at about 60 psi, a 1½ in. main is adequate.
4. With high-pressure boilers working at more than 60 psi, e.g. up to 120 psi, a 1¼ in. main can be used.

The reference to the 1¼ in. main needs amplification. With low-pressure boilers that 'blow-off' at 15 psi, the main *must* be large enough to pass the full boiler output at about this pressure because it cannot be raised any higher. But with a high-pressure boiler that can be worked at pressures up to 120 psi, if the full output of steam cannot be passed by the main when the pressure is 60 psi, it *can* be passed merely by letting the boiler pressure rise just sufficient to overcome the extra frictional resistance of the main. In other words, the limiting factor with low-pressure boilers is main size, which must be adequate, whereas with high-pressure boilers the limiting factor is boiler pressure: any size of main can be used within the pressure range of the boiler.

Table 3

PRESSURE REQUIRED AT THE BEGINNING OF A MAIN TO GIVE A STEAM FLOW OF 1,200 LB./HR.

Size of main (internal) dia.	Length of main					
	20 ft.		100 ft.		200 ft.	
	4 pipes*	8 pipes	4 pipes	8 pipes	4 pipes	8 pipes
3 in.	15	**9**	15	**9**	15	**9**
2 in.	24	**9**	24	**13**	24	**15**
1½ in.	24	**14**	38	**26**	48	**40**

* Hoddesdon pipes.

Heavy type indicates 'balanced steaming' (page 91).

Three features of great interest are brought out in Table 3. We have seen that the only function of boiler pressure is to overcome the frictional resistance of the main and hoses so that the full output of steam may be delivered to the soil. Thus, the main itself need not and should not be a 'bottle-neck.' Now, between the end of the main and the soil comes the steaming apparatus, say Hoddesdon pipes. Obviously, if there are not enough holes in these pipes (i.e. not enough pipes) to pass the full output of steam, the pipes themselves will be a bottle-neck and the quantity of steam delivered to the soil will be cut down, however big the main.

This is very clearly seen in Table 3, for the flow of steam is constant for all the examples given. Consequently, if the

Hoddesdon pipes are a bottle-neck, a *higher boiler pressure* will be required to force the steam into the soil and this is precisely what is seen if the figures for four Hoddesdon pipes are compared with those for eight pipes. In actual practice, the situation is the other way round: a given boiler works at a given pressure so four pipes will then deliver *less steam* than eight pipes.

This brings us to the second feature of interest in Table 3. We saw earlier that soil cannot condense steam efficiently at a rate greater than about 18 lb. steam/sq. ft./hour, i.e. a rather low rate of supply. Now, if four pipes are insufficient to pass the full boiler output of steam at a given pressure, it is not a satisfactory solution to raise the pressure and thereby force more steam into the soil, because the steam would then be flowing into the soil faster than it could be utilized efficiently, i.e. faster than 18 lb./sq. ft./hour. The correct solution is to use more pipes and get rid of the bottle-neck that way. How well this can be done is seen by examining the figures for eight pipes in Table 3, for, in this experiment, eight is the number of pipes required to supply 18 lb. steam/sq. ft. soil/hour when the boiler output is 1,200 lb. steam/hour and the pipes are spaced 18 in. apart in the soil.

The third feature of interest in Table 3 refers to the boiler pressure required when a 1½ in. main is substituted for a 2 in., or the length of main is increased from 100 ft. to 200 ft. When the Hoddesdon pipes are a bottle-neck, *as they almost always have been in the past*, a substantially higher boiler pressure (e.g. 48 psi instead of 38 psi) is required to overcome any further restriction imposed on steam flow by lengthening the main. Similarly, a substantial increase in boiler pressure (e.g. 48 psi instead of 34 psi) is required when the diameter of the main is decreased. But when the correct number of Hoddesdon pipes is used for a given area of soil and the bottle-neck thereby removed, Table 3 shows that the maximum boiler pressure required to deal with a longer main, etc., is no longer substantial but quite moderate. This is true for a main 300 ft. or more long, or for one only 1¼ in. diameter.

We can now begin to see why it was thought necessary to use 'high-pressure' boilers in the past. Small-diameter mains and hoses, e.g. 1¼ in., have been employed *together with steaming* *apparatus* that has bottled up the steam: there has been restriction of steam flow (quantity) all along the line.

One last point on steam pressure. If books on the use of steam in industry are consulted, there will be found tables giving the 'pressure drop' along given lengths and sizes of pipe at given boiler pressures. These figures are entirely relevant for processes where steam is used *at pressure* at the end of the main, e.g. to drive an engine; that is, where steam velocity in the main is low relative to that in a sterilizing main. But such pressure-drop figures are entirely irrelevant for soil sterilizing for there is practically no pressure at the end of the main and steam velocity is high. Thus, pressure drop can be put into the same category as super-heat and steam wetness: none of these is of any importance in soil sterilization.

To sum up. 'High pressure' has been a will-o-the-wisp in the past, luring the grower deeper and deeper into the morass of misunderstanding and bad practice. Perhaps we may think of 'low pressure' as the light, carried by the research worker, that will lead to the firm ground of understanding and good practice. Consider its merits. It has long been known to heating engineers that, in theory, the lower the boiler pressure the more efficiently will the boiler convert water to steam. In addition, the lower the pressure in the main, the less heat will be lost from it. Finally, at low pressure, more latent heat is available per lb. of steam and more heat can be obtained from condensation. The Ministry of Fuel and Power (11) have put the issue in a nutshell—'*Use the lowest possible pressure for process and heating*.'

Thus, from all points of view, it is not *high* boiler pressure which we must look for to achieve efficient soil sterilization, but the *lowest* pressure commensurate with ease of handling the steaming equipment. Boiler pressure is merely an aid to 'pushing' the required amount of steam through the mains. Used indiscriminately or ignorantly pressure may be a handicap instead of a help to efficiency.

SUMMARY

1. The amount of heat required to raise the temperature of 1 lb. water from 32° F. to 212° F. at atmospheric pressure is 180 British Thermal Units (Btu). This is called *sensible* heat.

2. The amount of heat required to change 1 lb. water at 212° F. into steam is 970 Btu. This is called *latent* heat and is the heat available for soil sterilization.

3. Steam, in the absence of water, can be heated to more than 212° F. and is then said to be *super-heated.* Super-heat can be ignored in the practice of soil sterilization.

4. Steam at boiling point is called *saturated steam* if it contains unevaporated water droplets. Pure steam at boiling point is called *dry saturated steam.* There is no practical advantage in contriving a supply of dry saturated steam for soil sterilization, but water condensed from the steam in mains should be removed.

5. Steam used in soil sterilization is generated at pressures varying from 10 to 120 psi and the amounts of sensible and latent heat vary with steam pressure. Nevertheless, the heat available in sterilizing may be taken to be independent of steam pressure.

6. Thus, the supply of heat (steam) for soil sterilization is uncomplicated by considerations of super-heat, wetness and pressure.

7. Quantity of steam, not mere pressure, is the chief requirement for efficient sterilizing. Pressure is necessary only to get the required quantity of steam to the soil through a given size and length of main. Examples, from experiment, are given and their meaning and application discussed.

CHAPTER 8

STEAM: ITS ACTION

WE now come to the fundamental factor in steam sterilization, namely, in what manner the heat carried by the steam is transferred to the soil (12).

We will suppose the steam is being supplied to a soil in good tilth, evenly and from below. At the points of entry, the steam drives out and replaces the air in the pore spaces and heats the soil particles by condensing on their surfaces and giving up its latent heat. Steam readily condenses on the cold surfaces of the particles and will not force its way past them so long as they are capable of absorbing heat. Consequently, the soil is heated in layers, such that at any given moment there is a layer not more than 1 in. thick being heated, with cold soil above it and hot soil below. If the steam is being supplied through the holes in a perforated pipe, heating proceeds upwards and sideways and downwards, too, provided the soil is loose enough. Eventually the heated portions join up to form a horizontal layer as before.

Whatever the method of supplying steam to soil from below, a heated layer (heat front) is soon formed and rises progressively from the bottom to the top of the soil from which the steam will escape wastefully if it is not promptly turned off. The rate at which the heat front rises depends on the amount of heat required to raise the temperature of the soil and on the rate at which steam is supplied.

The reader can quite easily prove that heating proceeds by layers, by carefully touching with the flat of his hand the surface of the soil being sterilized. He will find that the surface is quite cool until, suddenly, it is scalding hot.

So much for the way heat rises in soil to which steam is being applied from below. But when steam is supplied by means of a pipe buried, for instance, in glasshouse soil, does the heat travel downwards as well as upwards? It does, but in a limited fashion. For example, if the soil beneath the pipe has been well loosened to a depth of 6 in. by forking, the heat will penetrate this 6 in. depth and effect sterilization. But if the soil beneath the pipe is not loosened, then the heat will penetrate little more than 1 in. The importance of this is twofold. First, if pests or disease are present in the subsoil to a serious extent, then there can be no substitute for burying the pipes deeply. Secondly, forking loose the soil below the steaming pipe is well worth while: the extra labour is little, the extra depth sterilized is much, e.g. 50 per cent, when the pipe depth is 12 in.

One other point. Glasshouse soils are rarely 100 per cent friable and lumps may occur up to 2 to 3 in. in diameter. What happens to these in the process of heating? The steam condenses at once on the outside of the lumps and gives up its heat. But because the steam has great difficulty in penetrating into the small pore spaces in a dense lump and because soil is a poor conductor of heat, it takes a relatively long time for heat to travel from the outside of a lump to its centre. Thus, whereas at the end of, say, 15 minutes' steaming of glasshouse soil all the finer particles will have reached a temperature of 212° F., only the surface layers of the larger lumps buried in the soil will be hot. Experiments (13) have shown that so long as such lumps are covered by at least 2 in. of fine soil at 212° F., heat continues to pass slowly into the lumps from the surrounding soil (even after the steam is turned off) until finally it reaches their centres and they are sterilized right through. What about lumps on the surface of the soil? The answer is obvious. Provided the surface is covered by a good steam- or heat-retaining material before steaming begins and this cover is kept on for a sufficient length of time *after* steaming has ceased (page 106), then the heat will eventually penetrate to the centres of the lumps and sterilization will be complete.

It will now be clear that four precautions are essential for the quick and efficient sterilization of lumpy soil. The *first* is to sieve or cultivate it until no lumps remain larger than $\frac{3}{8}$ in. diameter in the case of potting soils and $1\frac{1}{2}$ in. diameter, preferably less, with glasshouse soils. The *second* precaution is to ensure that the soil is uniformly loose to encourage rapid and even penetration of the steam, especially downwards. The *third* precaution is to see that the surface of the soil is level, so that the heat front reaches the whole of the surface at approximately the same moment, without leaving cold areas here and there. The *fourth* precaution is to cover the soil with a suitable steam- or heat-retaining material (page 151) to make certain that, after the steam has been turned off, the heat from the bulk of the soil below will maintain the temperature of the surface layer at not less than 180° F. for at least 10 minutes. The lumps will then look after themselves.

The rule for successful sterilizing, based on the action of steam, can be stated in one sentence. Watch the subsoil; watch the surface soil, *especially the latter.*

We have now seen the way in which the heat carried by the steam is transferred to the soil. In practice, the pattern of events is modified by the nature of the soil. There are two main factors in this modification, namely, the time required for (1) the steam to reach and fill, one by one, the spaces between the soil particles (crumbs), and (2) the heat from the steam to penetrate, one by one, the particles themselves.

Each of these classes can be subdivided. The time required for the steam to fill the pore spaces depends on the volume moving into the pores and on their size and number. The time required for heat to penetrate the soil particles* depends mainly on their size and the amount of moisture they contain: the more the moisture, the longer the time required for penetration and heating.

We can summarize these four factors as follows: The efficiency of steam in heating soil depends on:

1. Size and number of pore spaces.
2. Rate of supply of steam into pore spaces.
3. Size of soil particles.
4. Moisture content of soil particles.

Items 1 and 3 are, of course, interdependent.

If we now look at some examples of steam sterilization, we shall not only see just how these four factors apply in practice, but we shall also understand exactly what is required for efficient sterilization.

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* The nature of the particles also counts, i.e. whether they are of clay, sand, humus, etc.

Steam sterilization is LEAST *efficient when:*

1. The pore spaces are so small as to obstruct steam penetration, e.g. heavy clay and fine, silty soils.
2. The steam supply is excessive and enters the pore spaces above the maximum rate.
3. The soil (even though of good structure) is sufficiently compacted, naturally or artificially, to reduce the size and number of the pore spaces below the point necessary for their rapid filling by steam.
4. Particle size is sufficiently large (e.g. lumps) for heat to take an unduly long time to penetrate the particles completely.
5. The soil is too moist or wet.

A moment's thought will now enable us to see the converse situation.

Steam sterilization is MOST *efficient when:*

1. The soil is in good tilth or has been sifted to give suitable particle size.
2. The soil has been artificially loosened to allow the steam to fill all the pore space in the minimum time.
3. The soil is *dry*.

In other words, we shall obtain maximum efficiency of steam sterilization when steam at the correct rate of injection is brought into contact with the maximum area of *dry* soil particles.

You will notice that I have put the word 'dry' in italics. There is a special reason for this emphasis. It is this. The same amounts (weight) of different substances require different amounts of heat to raise their temperature by a given figure. The substances are said to have different *specific heats*. The specific heat of water is defined as 1·0 and the values of all other substances are expressed in relation to this figure. Thus, if a substance has a specific heat of 0·5 then, compared with water, only half the amount of heat is required to raise its temperature by 1° F. We can put this another way and say that the substance will heat up twice as quickly as water for a given amount of heat.

Now, the specific heat of an oven-dry, mineral soil is approximately 0·2, only a fifth of that of water. It makes little difference whether the soil is sandy, loamy, or clayey. What really matters about soil is its moisture content because it takes about five times as much heat to raise the temperature of the moisture present in the soil as it does to heat the soil itself. The wetter the soil, the longer it takes to heat it and the more the heat required. Thus, wetness can increase the heat requirement by as much as 50 per cent for light soil and 100 per cent for heavy. A medium loam which any grower would describe, without hesitation, as dry will have a moisture content of some 20 per cent. *Very often*, gardeners and growers may be found sterilizing such soils with moisture contents as high as 30 to 35 per cent and therefore requiring some 50 per cent more heat (fuel). The reader can judge for himself how much fuel and time are needlessly wasted by such inefficient and ignorant practice. And this is quite apart from the deterioration of physical condition which follows the steaming of over-moist and wet soils.

Experiments have shown, in fact, that up to 5 lb. steam/cu.ft. soil can be saved by first drying out the soil.

SUMMARY

1. Soil is heated by the condensation of steam to water with a consequent release of 970 Btu of heat per lb. steam. Starting at the point where the steam is injected into the soil, heating proceeds in layers, mainly upwards and sideways, about 1 in. thick. Heat penetrates downwards very little unless the soil is thoroughly loosened.
2. Heat penetrates lumps of soil slowly, but provided the lumps are not larger than 1½ in. in diameter and are buried at least 2 in. deep in fine soil, the heat will eventually reach their centres, completing sterilization.
3. Sterilization of the surface layer and any lumps it contains is ensured by covering the soil with a steam- or heat-retaining material for at least 10 minutes after the sterilizing temperature has been reached and the steam is turned off.
4. Steam acts most effectively in heating soil when the soil is (1) dry, (2) loose, and (3) sifted or well broken up.
5. Soil which is not dry may commonly require from 20 to 50 per cent more heat, hence fuel, to accomplish sterilization.

CHAPTER 9

HEAT REQUIREMENT OF SOILS

WE saw in the last chapter that it takes approximately five times as much heat to raise the temperature of a given weight of water by 1° F., as it does the same weight of oven-dry soil. So the amount of heat required to sterilize a soil depends mainly on its moisture content. But the amount of water a soil will hold depends on its physical characteristics, clay soils having a higher capacity than sandy soils.

Calculations based on laboratory tests (14) have given the following results (Table 4 and Fig. 7) for the heat capacity* of a sandy soil (lower greensand) and a heavy clay (gault). 'The figures refer to a cubic foot of firm soil as collected. The words "dry" and "wet" indicate the extreme range of moisture content likely to be encountered, measured as a percentage of oven-dry weight. The "dry" soil had the appearance of being completely dry and further drying would require the application of artificial heat. "Wet" is the wettest state which could be maintained in a soil which is only moderately well drained and much too wet for satisfactory sterilizing.'

Table 4

THE HEAT CAPACITY OF SOILS

	Light soil		Heavy soil	
Soil condition	Moisture content %	Heat capacity Btu/cu. ft./°F.	Moisture content %	Heat capacity Btu/cu. ft./°F.
As collected (dry)	9	24	19	27
Saturated and drained (wet)	26	38	58	53

Two points of special interest emerge from inspection of Table 4 and Fig. 7. First, it will be seen that the heavy soil contains more than twice as much water as the light one, at both dry and wet extremes, hence it is especially important to attempt to 'dry out' heavy soils before sterilizing them. Secondly, the figures indicate the large saving in fuel that can be obtained by ensuring that the soil is as dry as possible. It should not be overlooked that, even when the steaming process itself is as efficient as possible, excess moisture in the soil can substantially increase the fuel bill.

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* i.e. the amount of heat necessary to raise the temperature of 1 cu. ft. of *firm* soil through 1° F. (Btu/cu. ft./°F.).

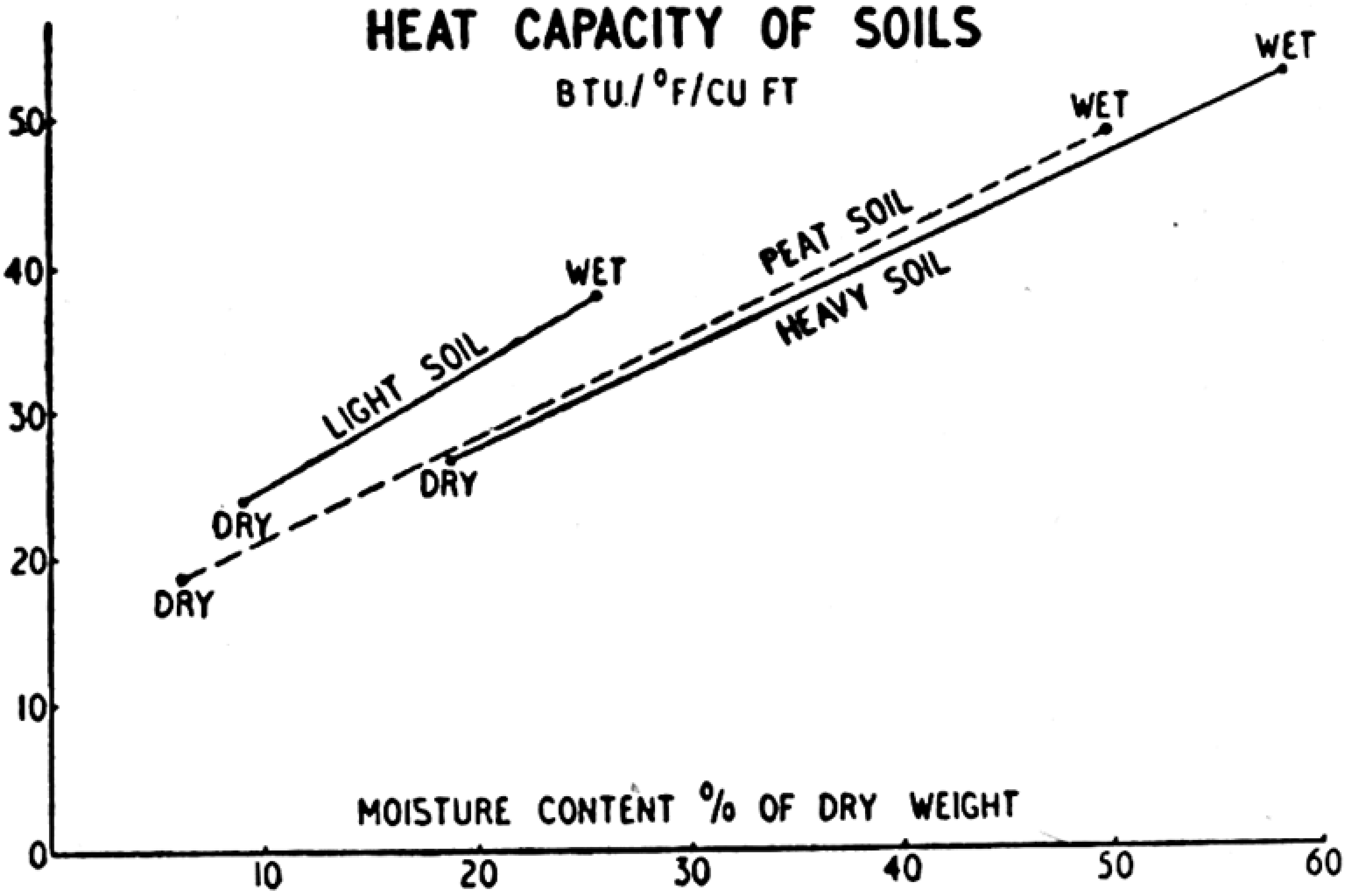

FIG. 7.—Showing the heat capacity of extreme types of soils, viz. sandy soil (greensand) and clay soil (gault). Note influence of moisture content.

Now, Table 4 gives the amount of heat required to raise the temperature of the soil by 1° F. If we assume that the temperature of a glasshouse soil just before it is sterilized usually lies between 40° F. and 55° F. (4° C. and 12° C.) then the temperature must be raised by some 150° F. to 170° F., i.e. to 212° F., to achieve sterilization. The amount of heat required to do this is given in Table 5. The figures are rounded off to the nearest hundred.

Table 5

HEAT REQUIRED TO STERILIZE SOILS

	Btu required to raise temperature of 1 cu. ft. of soil by 150–170° F.	
Soil condition	Light soil	Heavy soil
As collected (dry)	3,600–4,100	4,100–4,600
Saturated and drained (wet)	5,700–6,500	8,000–9,000

Taking the heat content of 1 lb. of steam as 1,000 Btu, we see that the theoretical heat requirement of soils ranges between the extremes of 4 to 9 lb. steam/cu. ft.

In practice some steam is bound to be wasted. Thus, in the highly efficient John Innes High-Rate Sterilizer (page 60) it was found (15) that, owing to the unavoidable leakage of steam under the boards and up the sides of the walls, an average of 6 lb. steam was required to raise the temperature of 1 cu. ft. soil from 54° F. (12° C.) to 212° F. In glasshouse soils, steaming must be continued until all the soil is *judged* to have reached 212° F., so, once again, steam is unavoidably lost, partly because steaming must go on until no cold spots remain and partly because of errors in judging how soon to turn off the steam. In full-scale experiments (9) on a medium heavy loam soil, the steam used varied from 5 to 12 lb. steam/sq. ft. soil surface when the soil moisture contents ranged from 21 to 37 per cent.

Trickle Steaming

For many years growers have been advised to continue full steaming for a further 10 minutes or so after the glasshouse soil has reached 212° F., to ensure thorough penetration of the heat, especially around foundations and dollies. Such a practice may double the fuel requirement, most of the steam merely passing through the hot soil without condensing, to fill the house with clouds of vapour. This waste of steam and fuel is so very obvious that more than a few growers reduce the flow of the steam to a 'trickle' once the soil has reached 212° F. If additional steaming is to be practised at all (page 106), then to economize fuel it should be by trickle steaming.

Target Steam Consumption

In general, it may be accepted that 6 lb. steam is required to raise the temperature of 1 cu. ft. of soil to 212° F. in an efficient bin sterilizer or in efficient steaming of glasshouse soils. At present, the amount of steam used ranges from 6 lb. (rarely) to 12 lb., with a probable average of 8 to 9 lb./cu. ft.

Fuel Requirement

Assuming that the best overall thermal efficiency with existing equipment is 41 per cent (12), it so happens that the Btu values given in Table 4 correspond to the same number of tons/acre of solid fuel, viz. 24 to 53 when the soil is sterilized to a total depth of 23 in. (pipes 18 in. deep). For a depth of 18 in. (pipes 12 in. deep) the approximate fuel requirement is obtained by reducing the values in the table by one-third, giving 16 to 35 tons/acre.

As pointed out earlier, these fuel figures are calculated from experiment. In current practice the lower values would be larger and a recent survey has shown that actual solid fuel consumptions vary from 27 to 40 tons/acre, according to soil conditions. It seems, therefore, that target fuel consumption using modern methods of sterilizing (Chap. 13, page 91) may be thought of for the time being as 25 to 30 tons/acre.

SUMMARY

1. The heat requirement of a soil is mainly determined by its moisture content.
2. Heavy soils have a higher capacity for moisture than light soils, therefore, they have a higher heat requirement. It is important, therefore, to take pains to dry out a heavy soil before it is sterilized.
3. The calculated heat requirements (extremes of dry to wet) are 3·6 to 6·5 lb. steam/cu. ft. soil for a light, sandy soil and 4·1 to 9·0 lb. for a heavy clay soil. In practice the lower values will be larger than these owing to the unavoidable wastage of some steam.
4. The recommendation to continue steaming for a further 10 minutes after the soil has reached 212° F. wastes much fuel. Trickle steaming should be entirely adequate.
5. In general terms, efficient (target) steam consumption for sterilizing soil in both bins and glasshouse beds may be accepted as 6 lb. steam/cu. ft. soil. At present it is 8 to 9 lb. or more.
6. Similarly, the target fuel consumption in the sterilization of glasshouse soils may be thought of for the time being as 20 to 25 tons/acre. Present consumption is 27 to 40 tons/acre.

CHAPTER 10

STERILIZING AT HOME

FOR the home gardener who wants to raise relatively few plants—say some tomato, pot or bedding plants—soil sterilization by steam is simple and inexpensive. Two methods are given below. In each, rapid but thorough treatment is the aim.

Saucepan method (6 *pints*). Sieve the soil through a ¼ or ⅜ in. sieve, spread the soil out thinly, under cover, for several days until it is approaching *dust-dry*. Take* the saucepan and pour into it a *measured* ½ pint of water (page 161) and heat rapidly on gas or electric cooker; immediately water boils, fill saucepan with soil to within ½ in. of the top; put on lid and using a 'minute timer' continue boiling for precisely 7 minutes. Remove saucepan (without taking the lid off) and stand for a further 7 minutes. Pour out soil thinly on to a clean surface to cool. When it has cooled mix it into a compost, or alternatively, store in a clean container until required. Do not allow the soil to dry out again and, if necessary, moisten it a little with tap water.

The saucepan method is safe and efficient because the amount and depth of soil are small and steaming can be controlled with ease. A 3-pint saucepan can also be used in which case the boiling time is reduced to 3½ minutes but the standing time of 7 minutes retained as before.

Trough method (½ *to* 1 *bushel*). By repeated use of the saucepan method a fair amount of soil can be treated with ease in a short time. However, the amateur whose requirements are on a somewhat larger scale may prefer to use a bigger sterilizer. If he is a handyman he can construct an efficient model (Fig. 8) by observing the following points:

1. The trough model consists essentially of a perforated soil container which fits snugly into, or on to, a trough in which water is boiled to produce steam.

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* Male readers: in the interests of matrimonial harmony, for 'take read 'arrange to be allowed to have.'

2. The soil container should be shallow, say 4 to 8 in. deep, in order to expose as large a soil surface as possible to the steam; and to avoid compaction of the soil by its own weight.
3. The perforated bottom of the container should offer the easiest possible passage to the steam. An $\frac{1}{8}$ in. mesh, round sieve or thin perforated metal (e.g. zinc) sheet may be used. Coarse sacking or similar material of $\frac{1}{8}$ in. mesh is also satisfactory. Sacking and sheet metal will need supporting on cross-bars. A sieve can be supported by its rim.

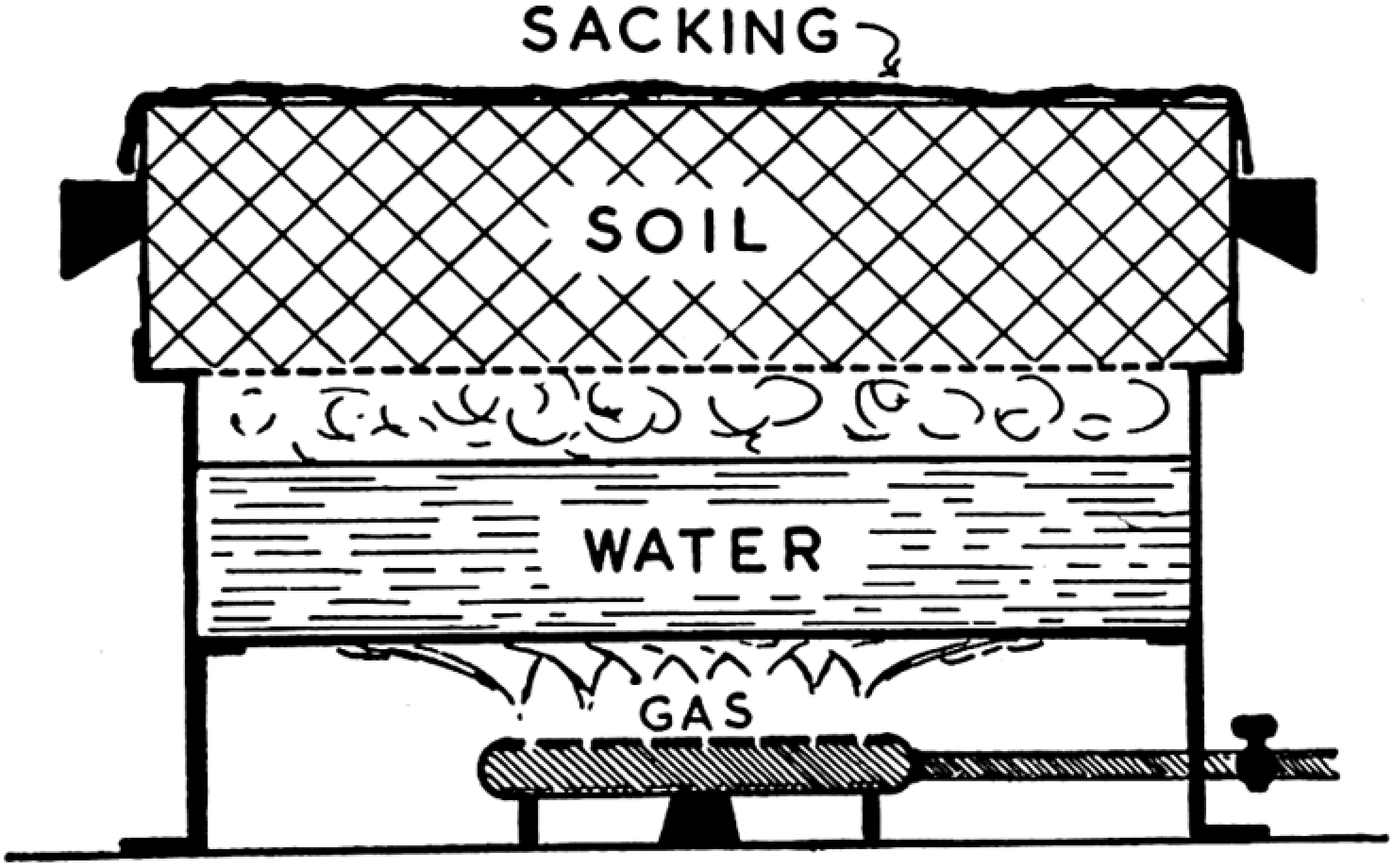

FIG. 8.—Diagram of a home-made 'trough' steam sterilizer holding approximately 1 bushel of soil. Soil container 21 in. square by 5 in. deep.

4. Whatever the kind of container employed it should fit fairly tightly into or on to the water trough. The aim is to ensure that as much of the steam as possible goes through the soil and as little as possible escapes from the junction of the soil container with the trough. In achieving this, care should be taken to see that steam pressure is not built up in the trough.
5. To ensure sterilization of the surface of the soil it must be covered with thick sacking or a moderately tight-fitting lid (cf. a saucepan lid) through which a hole is made to permit a thermometer (see page 89) to be pushed into the top inch of soil.

As with the saucepan method, the soil to be sterilized must be *dry*, sifted and loose. Sterilization is complete when the temperature of the top inch of soil is 212° F.

Small proprietary steam sterilizers are available for use with solid fuel, gas or electricity, at a cost of £3 to £6.

Other Methods

When it is not possible or convenient for the home gardener to use steam sterilizing apparatus, two other methods of sterilizing are available, viz. by electricity or by chemicals. Information on electrical methods is given in Chapter 15, and on chemical sterilizing in Chapters 16, 17 and 18.

Choice of Soil for Home Sterilizing

For most home gardeners it is 'Hobson's Choice': the soil must come out of the garden. The only advice which can be given is to avoid using soil that has just been limed or dunged.

Some gardeners prefer to buy loam. The main point to watch is that it is neither too light (sandy) nor too heavy (clayey) but a medium loam, preferably turf loam. Acid loams with a pH less than 5·5 should be avoided, also alkaline loams with a pH over 7·0. The ideal loam is *slightly* acid with a pH between 6·0 and 6·5. The choice and treatment for large amounts of loam is referred to on page 149.

SUMMARY

Two simple ways of sterilizing at home are described, the saucepan and the trough methods. The design of the trough sterilizer embodies a principle that should apply to all steam sterilizers in which the soil is treated in a container whether trough or bin viz. exposure to the steam of as large a soil surface as is practicable.

CHAPTER 11

STERILIZING IN BINS

THE two John Innes sterilizers described in this chapter are medium- to large-size models designed primarily for the use of the nurseryman who raises pot and box plants, i.e. who uses seed and potting composts. These sterilizers are the product of several years' research, followed by exhaustive testing under full-scale routine conditions at Bayfordbury. Various improvements have been made since the original models were described. As will be seen, the present models have the highest efficiency of their kind.

THE JOHN INNES LOW-RATE* STERILIZER

This sterilizer (Fig. 9) has been designed for the grower who wants to build a low-rate sterilizer of moderate size and low cost. It was conceived with four objects in mind: (1) heating efficiency; (2) strength of construction; (3) durability of materials; (4) low cost.

Maximum heating efficiency is obtained in this sterilizer by exposing the largest possible area of soil to the steam which heats it, and by the employment of good insulating materials to prevent the loss of heat to the outside air. These requirements are met by the use of reinforced brickwork for the main construction work. This is simple to follow and can be carried out by any handyman in the nursery, hence costs are low.

The sterilizer holds ½ cu. yd. of soil (10½ bushels) which, under average conditions, is sterilized in 30 to 45 minutes. Thus, allowing for the emptying and re-filling of the sterilizer, 4 to 6 cu. yd. of soil can be sterilized in an 8-hour working day.

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* Because of the widespread confusion deriving from the terms 'low pressure' and 'high pressure,' it is proposed to replace them with the more explicit terms 'low rate' and 'high rate,' since quantity of steam is the determining factor, not pressure.

The materials required to build the J. I. Low-Rate Sterilizer are listed below with the approximate current retail prices. The total of £38 is a maximum. Many growers would have on hand some of the materials required, e.g. bricks.

MATERIALS REQUIRED

1954 prices

	£	s.	d.
Bricks, Fletton pressed, 700	4	4	0
Firebricks, 30		17	6
Clean, sharp sand, ½ yard		6	3
Cement, 1½ cwt.		9	6
Hydrated lime, 1 cwt.		6	0
Silicia fireclay, 28 lb.		2	6
Perforated plate	8	0	0
Water trough	5	15	0
Strip-iron, 2 in. × ¼ in., two 2½ ft. lengths		1	9
T-iron, 1 in. × 1 in., four 4 ft. lengths		9	6
T-iron, 2 in. × 2 in., two 1¾ ft. lengths		3	6
Channel-iron, 1 in. × 1 in., two 1¼ ft. lengths		2	0
'Exmet' metal lathing, 24 gauge, 7 in. wide, 75 ft coil		18	6
Furnace bars, twelve 2 ft. long, 1½ in. wide	4	16	0
Furnace door and frame (frame 20 in. × 9 in. overall)	2	10	0
Smoke stack, cast iron, 12 ft. with elbow: 6 in. dia	5	14	0
Hot-house handles, 1 pair		2	0
Wood		10	0
Asbestos rope, 1 in., 9 coils (approx. 15 ft. per coil)	2	17	6
	£38	5	6

TOOLS REQUIRED

Bricklayer's trowel, hacksaw, a 1 in. cold chisel for cutting brickwork, and a pair of metal shears for cutting the metal lathing.

General Description

Figs. 10 to 15 show the main constructional work. The furnace is placed centrally at the front of the sterilizer. The hot gases are conducted by twin side-flues to the smoke-stack at the rear, thus ensuring a good distribution of heat. A steel water trough rests directly on top of the furnace and flues, and the steam from the boiling water percolates upwards through a perforated plate which forms the bottom of the shallow soil bin. This plate is cemented into the brickwork so that all steam must pass through the soil which, being shallow, is rapidly heated. The sill of the bin is high enough to allow the soil to be raked or shovelled into a barrow placed beneath it.

Three conditions are *indispensable*:

1. All brickwork must be properly bonded and grouted, taking special care at the four corners and around the furnace door.
2. Metal lathing must be used, at the points mentioned later, to reinforce the brickwork.
3. A mixture of 1 part of cement, 1 part of hydrated lime and 6 parts of clean sharp sand must be used for all brickwork.

Inattention to these points will lead to the heat of the fire splitting the walls.

SPECIFICATION

Overall size, 5 ft. 2 in. square, 3 ft. 3 in. high.
Soil bin, inside, 3 ft. 8 in. square, 1 ft. deep

Brickwork

1. Outer walls, 9 in. thick;
2. Inner walls, 4½ in. thick;
3. Furnace walls, 2 ft. long, 1 ft. 5 in. wide, 1 ft. deep.

Ironwork

1. Water trough, 3 ft. 8 in. square *overall*, 5 in. deep, ¼ in. mild steel, welded at corners, heavily galvanized.
2. Perforated plate, 3 ft. 10 in. square, ⅛ in. thick, mild steel, heavily galvanized, perforated $\frac{3}{16}$ in. holes at ⅜ in. centres, staggered. In three sections, two 18¼ in. and one 9½ in. wide.

3. Furnace bars, 2 ft. long by 1½ in. wide.
4. Smoke pipe, two sections each 6 ft. long, 6 in. diameter, and elbow with soot door.

Woodwork

Sliding board, 3 ft. 8 in. wide, 1 ft. deep, ⅞ in. thick.

CONSTRUCTION

Foundation

The sterilizer should be erected in a shed giving protection from wind and rain and affording plenty of clean floor space for handling the soil. It is assumed that the shed has a concrete floor upon which the brickwork is directly built. The dimensions for setting out the brickwork are given under 'Specification' above.

Courses 1 *to* 3

Lay as shown in Fig. 10. Next place in position the furnace door. Any suitable-sized furnace door may be used, provided

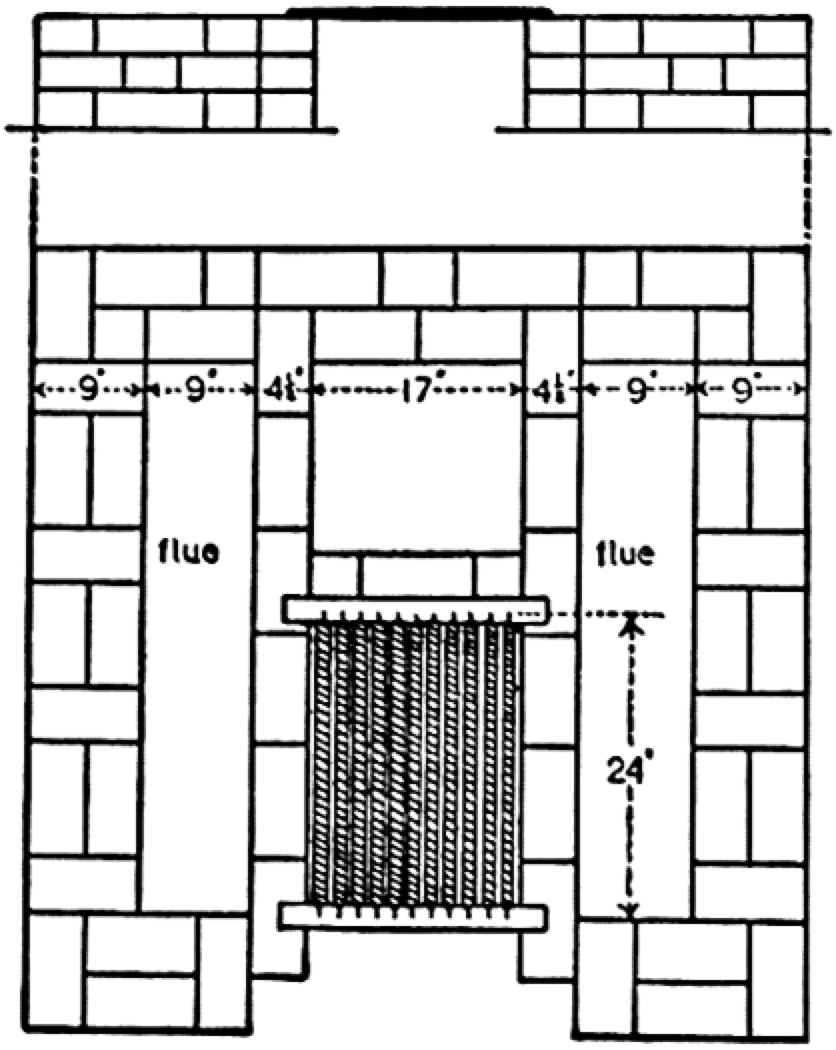

FIG. 10.—*Below:* Plan of third course of brickwork with furnace bars and bearers in position. *Above:* Front elevation, courses 1 to 3.

it is substantial. Alternatively, a simple door may be made from ¼ in. iron plate. It should be remembered that, depending on the size of the furnace door used, adjustments may have to be made to the adjacent brickwork. Immediately behind it, let into the brickwork of the third course the front bearer that carries the firebars. Fix the back bearer at the same level as the front one. The T-irons used for these should not be less than 2 in. by 2 in. or they may buckle under the heat of the fire.

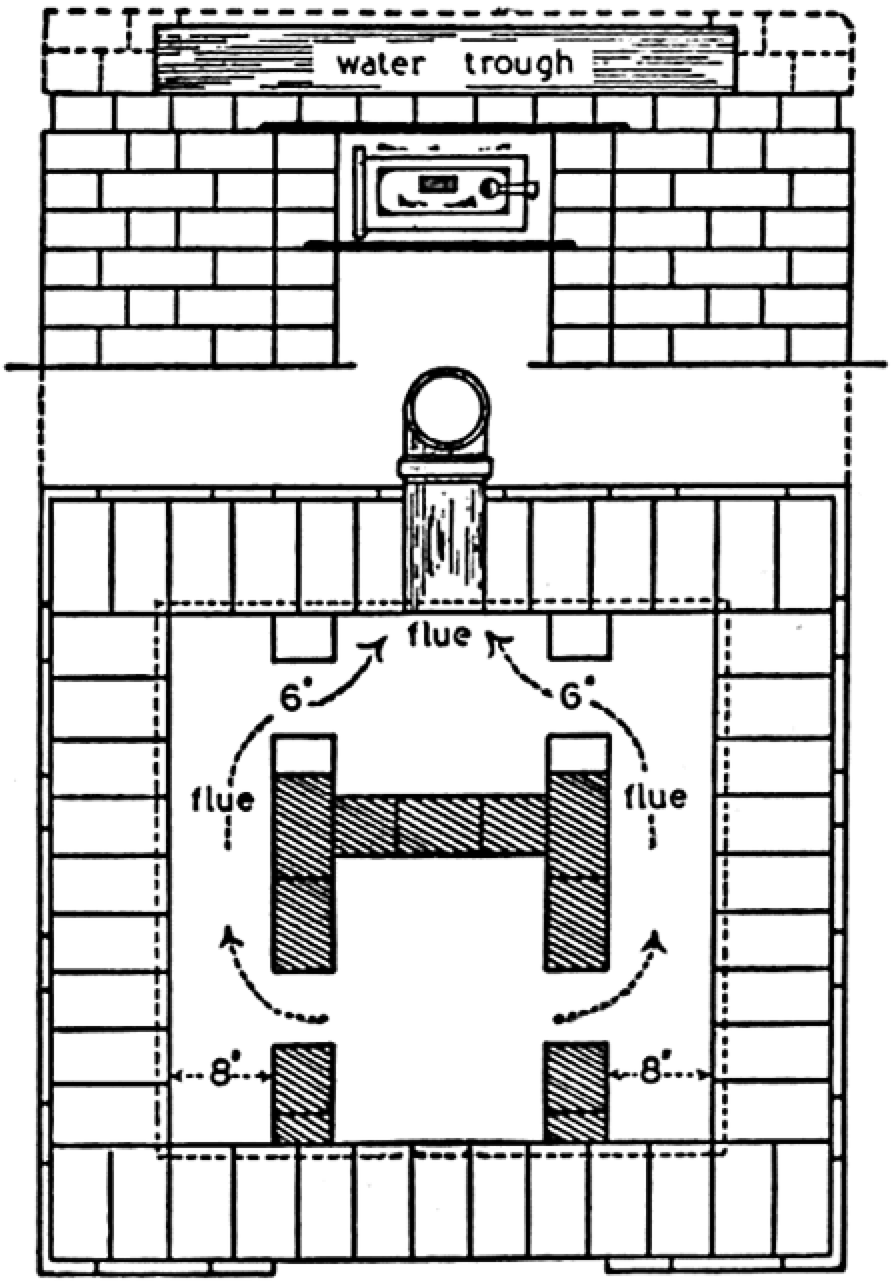

FIG. 11.—*Below:* Plan of seventh course of inset brickwork, of firebricks (shaded), and of flues. The position of the water-trough is shown by the dotted line. *Above:* Front elevation showing courses 1 to 7, and water-trough. Dotted lines show the position of courses 8 and 9. The black line above the furnace door indicates the position of the strip-iron which carries the seventh course of bricks over the furnace recess.

Courses 4 *and* 5

(*a*) *Inner Walls.* Use firebricks and fireclay (which should be soaked for several hours before using) for the side and back walls of the furnace (Fig. 11).

(*b*) *Outer Walls.* As courses 1 to 3. The elbow of the smoke-stack rests on the top of the fifth course of the back wall (see also Fig. 15).

Course 6

(*a*) *Inner Walls*:

(1) Furnace walls: lay firebricks as in courses 4 and 5.

(2) Continue the line of the furnace walls, using ordinary bricks, to join up and bond with the back wall of the sterilizer. Six-inch gaps are left midway between the rear of the furnace and the back wall to connect the side flues with the smoke-stack (Fig. 11).

(*b*) *Outer Walls:*

(3) Lay as in the fifth course.

(4) To span the furnace recess, lay the two 2 in. pieces of strip-iron across the gap ready to carry the seventh course (Fig. 11).

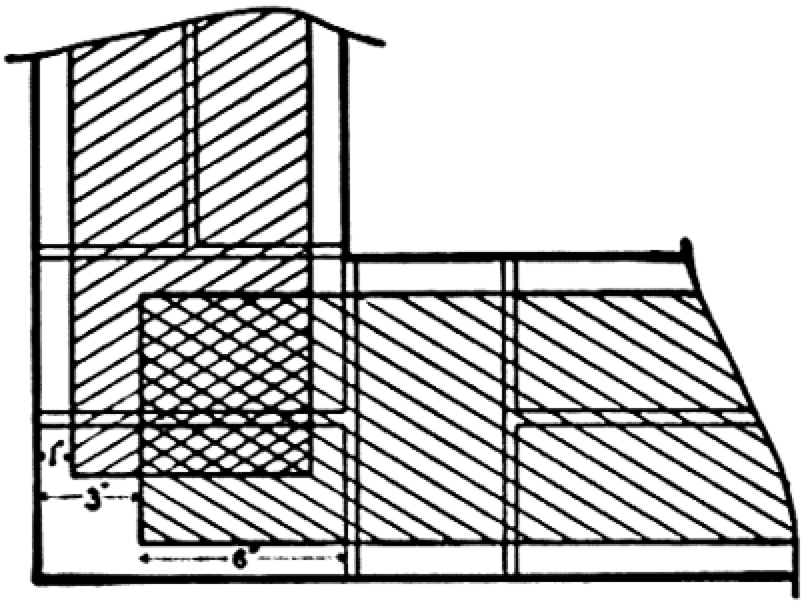

FIG. 12.—Showing how the metal lathing is overlapped at the corners of the outer walls.

(5) Next lay 'Exmet' metal lathing *all the way round* including the front. This takes 4 pieces, each 4 ft. 8 in. long. The pieces should overlap 5 in. at the corners (Fig. 12).

Course 7

(*a*) *Inner Walls:*

(1) Lay as in course 6 but leave 6 in. gaps midway on each side to connect with the side flues.

(*b*) *Outer Walls:*

(2) Project the bricks inwards to form a 1 in. ledge (Fig. 11). This ledge, together with the inner walls, supports the water trough. Care should be taken to see that the seventh course is dead level otherwise the trough will not sit squarely on all the walls.

(3) Place a single layer of asbestos rope all round the ledge. This is to prevent steam escaping around the sides of the trough into the flues.

(4) Carefully lower the trough into position on to the ledge. The trough should be exactly central (Fig. 11).

(5) Lay metal lathing all the way round the seventh course of bricks, as in the sixth.

Course 8

Lay the bricks as in the outer wall of courses 1 to 6, cutting ½ in. off their ends so as to leave a gap between the bricks and trough. Lay metal lathing all round.

Course 9

1. Lay bricks as in course 8. When the mortar has set, fill the gap left between the bricks and trough in courses 8 and 9 with continuous coils of asbestos rope and tamp down tightly. This is to prevent steam escaping around the sides of the trough into the flues. (If desired, zinc flashing, 7 in. wide and 15 ft. long, can be used as an extra precaution against escaping steam. The flashing is laid in one piece on the ninth course of bricks, with 2 in. of its width on the bricks and the other 5 in. bent down into the trough, tight up to the sides.)

2. The four T-irons which support the perforated plate have now to be spaced out, flat sides upwards, 9 in. apart. The ends of the T-irons fit into the gaps between the bricks of this course (Fig. 13).

3. To determine these positions, find the centre of the trough along the sill side. Measure 4¾ in. on either side of this centre; this gives the positions for the two middle T-irons which carry the removable section of the perforated plate. Now space the other T-irons 9 in. apart.

4. Next lay in position the perforated plate so that it overlaps the brickwork about 1 in. on all sides. Mark the position of the channel-irons (Figs. 13 and 14) at each end of the sill and chisel out the holes for them. The irons should touch the edges of the perforated plate on the sill side. To prevent steam escaping, the back of each channel-iron should be in line with and tight up against, the brickwork of courses 10 to 13. Note how the lower end of each of the channel-irons has been sawn and bent out to key into the brickwork. Cement the irons into position.

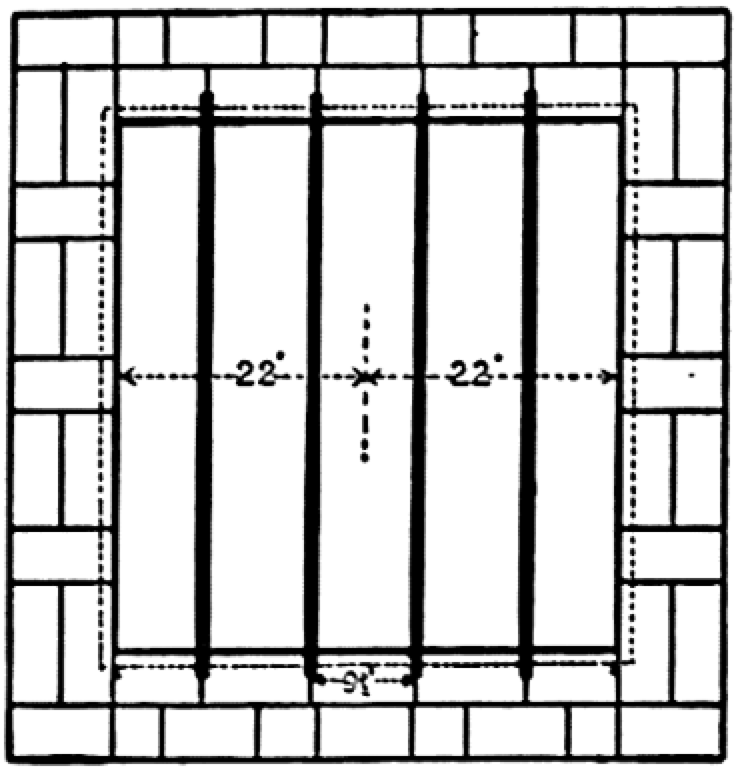

FIG. 13.—Plan of ninth course of brickwork, showing the spacing of the T-irons which support the perforated plate (dotted line).

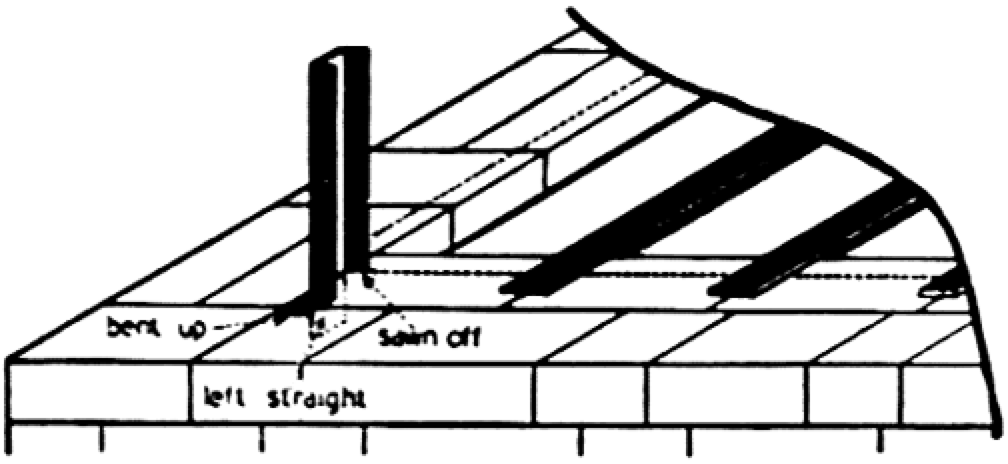

FIG. 14.—Shows position of channel-irons and method of fixing. Note how 2 in. of the lower end is sawn and bent out to key into the brickwork.

5. Spread a thick layer of lime-cement, 2 in. wide, all round the inner edge of the ninth course. On this, lightly place all three sections of the perforated plate. When these are properly fitted remove the centre section and firmly bed down the two outer ones.

6. Lay metal lathing all round the ninth course. The lathing should meet but not overlap the edges of the perforated plate, except on the sill where it should overlap by ½ in.

Courses 10 *to* 13

Lay these courses on three sides only, omitting the sill for the time being.

Sill

Float not less than 1 in. of a mixture of 1 part cement and 1 part of fine sand over the sill and its metal lathing so that it overlaps the perforated plate by 1 in. When the cement is half set bevel off the edge.

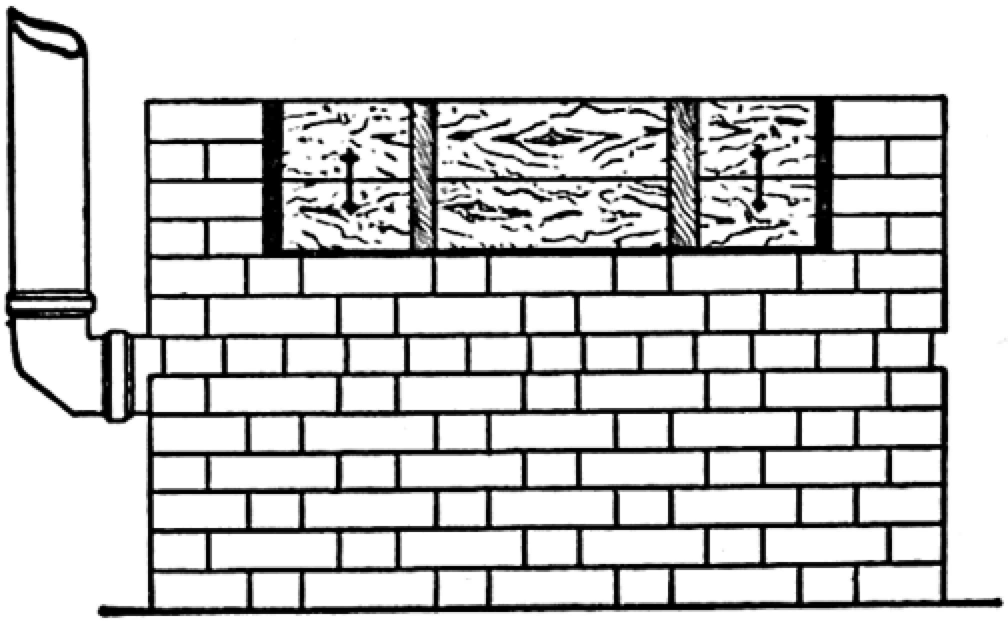

FIG. 15.—Side elevation of sterilizer showing position of smoke-stack and channel-irons (blacked-in) holding the sliding board.

Sliding Board

Construct as shown in Fig. 15.

Removable Section of Plate

As previously described, the 9½ in. centre section of the perforated plate is removable so that the trough can be got at and mud cleaned out. When the sill is finished the centre section is fitted by measuring the distance across the bin from the sill to the far side and cutting off 1 in. from each end of the plate. The section should fit snugly at each end without jamming.

GENERAL REMARKS

It has been difficult to describe briefly certain of the constructional details; nevertheless, all of the work is simple and straightforward, especially if the various parts are fitted into place before finally cementing or fixing them. If the sterilizer is to last, the building should not be hurried and great care should be taken to see that the cementing, bonding and reinforcing are thoroughly done. After the sterilizer has been finished, it should be left for *at least one week* to allow the cement to harden.

The perforated plate and water trough specified are of heavy quality, and in the case of the trough in particular, the use of less substantial material would be false economy, since it is the trough which is most likely to wear out.

The first time of operation only a gentle fire should be used or the brickwork may be damaged. Nurserymen have sometimes added their own refinements to the sterilizer, e.g., a water gauge, soot doors at rear of each flue.

OPERATION

1. The soil to be sterilized should have been stacked (26) and protected from rain some weeks ahead so that it is very *dry*. Moist soil cannot be sterilized efficiently in low-pressure steam sterilizers.
2. Sieve the soil through a $\frac{3}{8}$ in. sieve.
3. Fill the trough with water to a depth *not exceeding* 3½ in., so that there is no chance of the boiling water wetting the soil.
4. Cover the perforated plate with sacking, light the fire and bring the water to the boil. Remove the sacking and load the soil *loosely* and evenly into the bin to the full depth of 12 in. (fill to 6 in. only for the first time); cover with thick sacking.
5. Five minutes before sterilization is complete, make up the fire so that it is hot and bright when the next lot of soil is loaded into the bin.
6. Sterilization is complete as soon as all the soil (including the surface and corners) is 212° F. This takes 30 to 45 minutes with medium loams of moderately good crumb structure.

7. After each load of soil is sterilized, at once wash out with a syringe or hosepipe any soil blocking the perforations in the plate.

8. Fill the water trough to a depth of 3½ in.

9. Mud will gradually accumulate in the trough and must be raked out occasionally if the efficiency of working is not to be impaired.

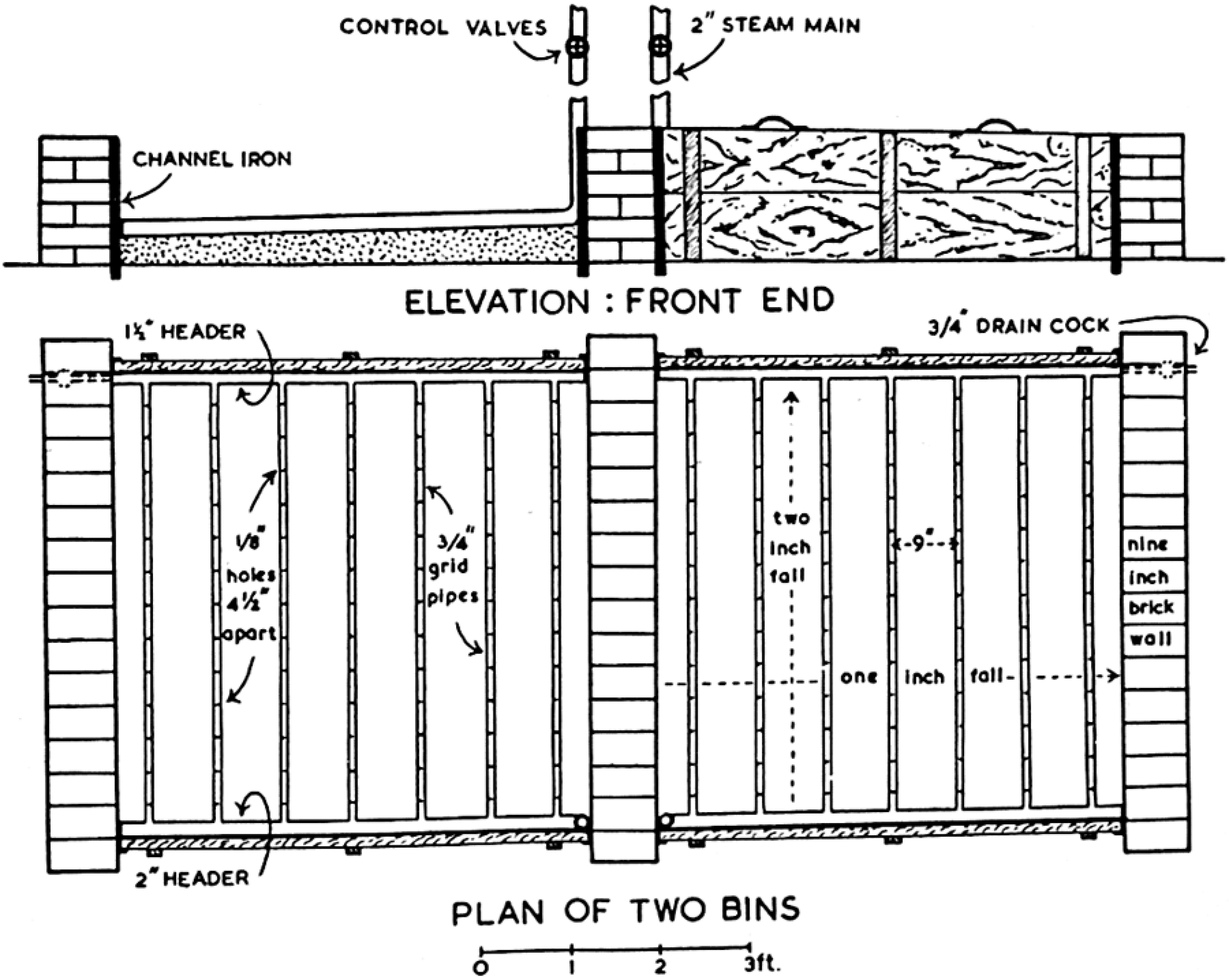

FIG. 17.—Plan and end elevation of John Innes High-Rate Sterilizer, two-bin model.

THE JOHN INNES HIGH-RATE STERILIZER

This sterilizer (Fig. 16) was designed for the medium- to large-size nursery requiring sterilized soil in larger quantities than can be handled conveniently by the J. I. Low-Rate Sterilizer. Two or more bins comprise the sterilizing unit, one bin being filled or emptied while another is being steamed. Using a boiler of appropriate size (see below) a two-bin unit has a maximum output of about 16 cu. yd. a day. It has four special features:

1. The number and size of grid pipes, headers and valves, are such as to enable a low-pressure boiler to be used.
2. The bin floor is sloped in two directions to ensure the rapid removal of condensate, before sterilizing begins, via a cock at the lowest corners.
3. The grid pipes are buried in concrete, (*a*) to prevent warping, and (*b*) to give a smooth shovelling surface.
4. The headers form an indestructible edge to the bin. Concrete edges quickly disintegrate from the combined effects of heat and shovelling.

MATERIALS REQUIRED

1954 prices

	£	s.	d.
Bins:			
(two, double-ended, each holding 1 cu. yd. soil)			
Bricks, Fletton pressed, 300	2	0	0
Cement, 5 cwt.	1	14	0
Builder's sand, ¼ cu. yd.		3	0
Clean, sharp sand, ¾ cu. yd.		10	0
Washed ballast. ¾ in., ¾ cu. yd.		8	0
Channel iron, 1½ in. × ¾ in.:			
four 1 ft. 8 in. lengths four 1 ft. 6 ins. lengths		11	0
Wood:			
(*a*) 1¼ in. roughboard:			
21 ft., 8 in. wide 21 ft., 9 in. wide	2	8	0
(*b*) 2 in. × 1 in. batten, 17 ft. length			
Tub handles, 4 pairs		8	0
Steam pipes:			
¾ in. pipes, 70 ft., for grids	3	4	0
2 in. pipe, 10½ ft., for inlet header	1	12	0
1½ in. pipe, 10½ ft., for lower header	1	4	0
two 2 in. gate valves, for control	5	12	0
two ¾ in. gate valves, for drainage	1	2	0
2 in. steam pipe to connect boiler with grids, say, 20 ft.	3	0	0
Drilling and welding	3	0	0
Total	£26	16	0

CONSTRUCTION

Figs. 17 and 18 show in diagrammatic form the main construction features of a pair of bins, each holding 1 cu. yd. of soil.

Foundation

Build the sterilizer in a shed that gives complete protection from wind and rain and has a good concrete floor. Allow plenty of clean floor space for handling the large amount of soil that can be dealt with in a day (Fig. 16).

Brick Walls

1. Erect three parallel 9 in. walls, each 6 ft. long, spaced 5 ft. 3 in. apart.

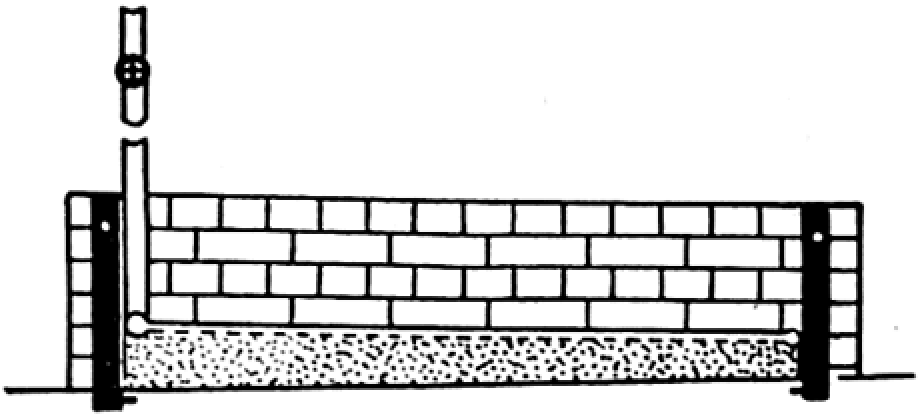

FIG. 18.—Side elevation of John Innes High-Rate Sterilizer.

2. Build the walls with a 2 in. slope from front (the high, or loading, end) to back: the middle wall 1 ft. 6 in. high at one end sloping to 1 ft. 4 in. at the lower end, and the outer walls 1 ft. 5 in. high sloping to 1 ft. 3 in.
3. Omit the odd bricks in the top course where the pins for the channel irons will later be inserted.
4. If the drainage cocks are to be housed within the outer walls as shown in Fig. 17, omit the relevant bricks until the grids are fixed in place.

Concrete Platforms

In the spaces between the walls, cast raised concrete platforms, 5 ft. 3 in. square. Make the platforms 6 in. high at the front sloping to 4 in. at the back adjoining the middle wall, and, correspondingly, 5 in. and 3 in. high adjoining the outer walls. Thus the platforms will have a double slope. Both at the front and the back, the platforms are inset about 4 in. with respect to the walls.

Steaming Grid

1. Construct *each* grid assembly from ¾ in. galvanized steam pipes and 2 in. and 1½ in. headers as follows:
2. Cut seven ¾ in. pipes, each 4 ft. 11½ in. long.
3. For the header at the front of the bin cut one 2 in. pipe about 5 ft. long only (to allow for a junction with the steam main or with a valve). Close the end of the pipe that goes next to the outer wall. For the header at the back of the bin cut one 1½ in. pipe 5 ft. 3 in. long and close the end that goes next to the middle wall.
4. Drill headers to take ¾ in. grid pipes at 9 in. centres. Position the pipes so that the centres of the outer two will be 4½ in. away from the brick walls when the assembly is finally put in place. Before cutting and welding the pipes, check that the *overall* distance from header to header will be 5 ft. 3 in. Weld the pipes to the two headers.
5. Drill ⅛ in. holes in each ¾ in. pipe at 4½ in. centres in a straight line along the top of the pipe. The end holes should be about 3 in. from the headers.
6. At the steam inlet corner of the grid, screw or weld on to the header a 2 in. riser to connect to the steam main.
7. Use a few cut bricks (not wooden blocks) to wedge the grid assembly accurately in place and pour fine concrete between the pipes so that the lines of ⅛ in. holes just show above it.

Mains and Valves

1. Run a 2 in. *overhead* steam main high enough to give ample headroom. Bring it down vertically over the front end of the middle wall and thence dividing to the 'sub-mains' feeding the two headers. Place the valves slightly above head level on the sub-mains (a third master valve may be installed with profit, nearer the boiler, to shut off steam from both bins).
2. Alternatively, run the main *underground*, just beneath floor level, to the front end of the middle wall and thence dividing

into the sub-mains feeding the steam headers. Insert the valves on the sub-mains at convenient points. A very neat job can be made by extending the middle brick wall to enclose the mains, and by fixing long stems to the valves so that their handles come just above the top of the wall. Where pipes go through brickwork, temporarily wrap them with layers of paper or other material to prevent brickwork cracking later from expansion of the pipes.

Channel Irons

1. Drill a $\frac{1}{8}$ in. hole, about 3 in. from the top of each channel iron, ready to take the pin which will fasten the irons to the brickwork.
2. Cut and bend up the bottom of each iron as shown in Fig. 18.
3. Chisel out holes, 2 in. deep, in the *floor* of the shed, tight up against the platform and bricks, to take the bottom end of the channel irons.
4. Accurately position the irons in the holes and against the brickwork and pour concrete into the holes. Allow to set hard.
5. Fix pins (between the top and second courses of bricks) in the places left for them in the brickwork, turning the far ends of the pins downward for an inch or so to ensure a secure fixing.
6. Complete brickwork.

Removable Boards

These, when in place, rest on the floor of the shed, not on the concrete platforms. Therefore, at the front of the bins the boards are 18 in. deep (two 9 in. boards) and at the back of the bins 16 in. deep (two 8 in. boards). See that the boards slide smoothly in and out of the channel irons.

Hints

Take pains with the assembling and positioning of the grids and channel irons.

Leave bins for *at least* one week to allow concrete, etc., to harden.

The steam mains should either be led to the grids in such a way that there is little risk of workers accidentally burning themselves on the pipes, or they should be suitably lagged.

Half and quarter cu. yd. sterilizers can be built by adjusting the proportions of the bins and grids, see Table 6.

If the bins must be built against the side of the shed, the sterilized soil will have to be emptied on to the floor area previously occupied by unsterilized soil (unless the treated soil is put straight into barrows and wheeled away). The risk of contamination is obvious. A remedy is the use of formaldehyde between each loading and unloading of the bins, a somewhat tiresome and messy business. The problem illustrates the necessity for careful thought before deciding on the location of bins. Quite convenient but risky, somewhat inconvenient but safe—which shall it be? Or is there a third solution? Every grower must decide for himself.

Table 6

BIN AND PIPE SIZES FOR THE J. I. HIGH-RATE STERILIZER

Bin, 12 in. deep			Internal diameter of headers	
Capacity (cu. yd.)	Internal dimensions	Number of grid pipes	Front (steam)	Back (condensate)
1	5 ft. 3 in. sq.	7	2 in.	1½ in.
½	3 ft. 8 in. sq.	5	1¼ in.	1 in.
¼	2 ft. 8 in. sq.	4	1 in.	¾ in.

OPERATION

1. A boiler is required to operate the bins. The time taken to sterilize a given quantity of soil is determined by the *amount* of steam the boiler can supply each hour. The larger the boiler, the quicker the soil is sterilized. The time taken by various sizes of boiler, under average working conditions, is given overleaf in Table 7.

Some steam pressure is necessary to get the steam from the boiler to the grids. A boiler pressure of 30 psi is sufficient to operate with maximum efficiency the J. I. High-Rate Sterilizer.

2. The soil to be sterilized should have been selected, stacked and *dried out* ready for use as recommended for the making of John Innes Composts (26).

3. *Sieve* the soil through a $\frac{3}{8}$ in. sieve or use a power-driven shredder or riddle to give the same particle size.

4. Open the drainage cock at the side of the bin and blow steam through the grid to (*a*) heat the pipes, (*b*) clear the holes of soil (check this carefully), and (*c*) remove water condensed from the steam. Close steam valve and drainage cock.

Table 7

BOILER SIZE AND STEAMING TIME WITH J. I. HIGH-RATE STERILIZER

Boiler size (lb. steam/hour)	Steaming time (min.)
1 cu. yd. soil	
1,500	6
1,200	8
1,000	10
800	12
650	15
$\frac{1}{2}$ cu. yd. soil	
600	8
500	10
400	12
300	15

Boiler sizes and steaming times have been calculated on the basis of 6 lb. steam/cu. ft. of soil. This figure has been obtained from the results of experiments with bins.

5. Without delay, pour the soil *loosely* and evenly into the bin. Level the surface with a shovel or rake, taking care not to compact the soil. Cover with heavy sacking.

6. Turn steam full on. Use a thermometer for testing the temperature of the soil. When it is 212° F. everywhere turn off steam and leave soil covered for a further 10 minutes.

7. Sterilize the mixing floor with a 2 per cent solution of formaldehyde applied with a rose-can.

8. Empty bin, scattering the soil widely in a flat heap to encourage rapid cooling. Avoid conical heaps: they store heat and, maybe, trouble.

GENERAL REMARKS

The J. I. High-Rate Soil Sterilizer is the most efficient steam sterilizer of its kind and the method of using it is unique in that it employs residual heat as part of the sterilizing process. The design, together with the use of residual heat, ensures the highest thermal and sterilizing efficiency. The techniques employed (the use of dry, sifted, loose soil and of rapid heating and rapid cooling) ensure that risk of damage to the soil and to the plant is eliminated.

PORTABLE BINS

An alternative to the brick sterilizing bins just described is the portable one made of heavy boards. A cubic yard bin consists of four boards, 12 in. deep, joined at the corners to make a square, 5 ft. 3 in. inside. The steaming pipes are in the form of a small grid (page 107) with the usual vertical riser at the back to which the steam hose is connected. The grid is lifted into the bin, the soil placed on top and steaming carried out in the usual way. When it is finished the bin is tipped up and over, the grid dragged out and the soil raked aside to cool (or the bin can be moved to a new spot for each steaming).

Though seeming a convenient method, the portable bin is apt to be a second-best arrangement. Condensate cannot be properly drained away and a good deal of steam is wasted. To be sure, capital costs are reduced, but it is arguable as to whether this is the proper criterion of what is 'worth while.'

MOBILE BINS

In the bin sterilizers so far described the steam is taken to the soil, which is treated in fixed bins. A useful alternative is to take the soil, in a truck or trailer fitted with a grid, to the steam supply. Then, after the soil has been sterilized it can be taken in the vehicle straight to where it is wanted without further handling. The design of the grids for mobile bins should be based on the principles already discussed. For trucks, say, 6 ft. long by 3 ft. wide, the grid should be the same as that used in the J. I. High-Rate Sterilizer except that only four ¾ in. pipes will be wanted. For trailers, say, 10 ft. long by 6 ft. wide, the two headers should be 2 in. and the steaming pipes 1 in. in diameter, the latter being spaced about 9 in. apart as before.

Cross-stays should be welded to the trailer grid to hold the pipes rigidly in position. In both truck and trailer the soil depth should not be less than 6 in. nor exceed 12 in. While the soil is being taken in the trailer to the steam supply, it is apt to shake down and become compacted, therefore it should be loosened up again with a fork to permit rapid penetration by the steam.

SEMI-STEAMING

The saucepan method (page 47), so it would seem, can be used on a larger scale by substituting a clean, water-tight metal drum for the saucepan. The correct amount of water is poured into the drum, viz., 6 pints per cu. ft. of soil, and the water brought to the boil. Dry, sifted soil is then poured into the drum and covered with heavy sacking. A moderately tight-fitting lid is a further advantage. So far, so good. But what next? The fire, or gas, is kept going and supplies an unknown quantity of heat for an unspecifiable time. Further, unless the drum is insulated, a lot of the heat that should have gone into the soil will be wasted on the surrounding air, especially if the drum is in the open and a wind is blowing. Finally, there is a very good chance that in the effort to sterilize the top layer of soil, the bottom layer will be dried out, overheated, perhaps burnt.

None of this makes much sense, does it? And it is certainly far from good sense even if we try to be precise by estimating the amount of water, fuel and time required. The whole thing is chancy, hit-and-miss, giving different results at different times.

Why bother to mention it then? Because slipshod sterilizing is cheerfully accepted by so many people that it is necessary to emphasize the foolishness of this practice.

The emphasis can be carried further, for there is another method of sterilizing which is worse than semi-steaming. And whereas semi-steaming is rarely seen, the other method is not uncommon. So, keeping in mind the information in Chapter 6, let us look at a method which is still tolerated—even praised—for two reasons. It is old. It is 'cheap.' Therefore, it is acceptable.

BAKING

The name is exact. The soil is baked, i.e. heated in a more or less dry condition, to oven temperatures. Soil-bakers have been evolved of various designs; large and small, deep and shallow, horizontal and vertical, simple and adorned. They all suffer from the same defects, namely overheating of the soil adjacent to the heat source, destruction of organic matter, and irregular heating of the bulk of the soil. Sometimes it is the practice to turn the soil over with a shovel after a certain period of heating and thus move the cold surface soil to the bottom and the overheated bottom soil to the top. In other cases, the soil is wetted at the beginning or at intervals to produce semi-steaming conditions. The sterilizing process may last anything from 1 to 12 hours, e.g. the whole of the night.

Some growers use baked soil with apparent success, especially with strong growing plants. But as a method of sterilizing soil required for general purposes, and seed sowing and seedling growing in particular, baking cannot possibly be recommended for the progressive grower with a modern nursery. It is insidious in its effects, it gives variable results, it can be dangerous.

Once, after I had expressed my views on soil-baking to some growers and advisers, one of them said to me, 'but you would agree that sterilization by baking is better than no sterilizing at all?' If you think about the point of view, the philosophy, that lies behind that question, you may come to see it as a suitable epitaph for all those who hoped for the best while courting failure. A hazardous occupation.

The hazard of baking exists because, hitherto, the process has been almost entirely uncontrolled. The hazard becomes negligible when adequate control is exercised. Thus, the electric immersion heater (page 124) is a modified form of soil baker which is acceptable because it is well designed and adequately controlled. Recently, a fully-automatic rotary soil sterilizer has been introduced in the U.S.A. in which an electrically driven drum holding one bushel of soil is heated externally by a flame. It is claimed that sterilizing is completed in 5 to 8 minutes, according to soil moisture content.

CHOICE OF SOIL FOR BIN STERILIZING

The sterilizing bin, correctly used, is a precision instrument. And correctly conceived, it takes its place in a sequence of precision operations directed to the making of seed and potting composts. This sequence begins with the choosing of a suitable loam and continues with the standardization of the loam in a stack so that, ultimately, it is in first-class condition for sterilizing and for making into a first-class compost.

The point of view should now be clear. Only the best is good enough, even on purely economic considerations. A poor soil is not changed into a good loam by using a good sterilizer. A good loam demands a good sterilizer; and a good compost a good loam. The requirements are reciprocal and they apply all the way along the line. There should be no weak link in the chain—anywhere.

THE STERILIZING AND MIXING SHED

Like so many other tools, materials and methods employed in horticulture, sterilizing bins cannot be detached, as it were, from the general scheme of things but must be fitted into the nursery economy. This principle of *fitting* the new tool or method into nursery operation is fundamental, yet few growers give serious thought to the matter. For those who have not been introduced to the John Innes method of incorporating bin sterilizing into nursery lay-out and operation, the following notes may illustrate the fundamental idea as well as the particular problem.

Bin sterilizing and compost making *must* be under cover for three reasons: in the open, (1) much heat is wasted, (2) soil cannot be kept dry and handled efficiently, and (3) adequate hygiene is impossible. It might be thought that all this was obvious. On the contrary, I have known it to be recommended that loam, peat and sand should all be stored out of doors, the loam 'protected' from rain by a tarpaulin. From personal experience, I can say that this is not good enough: most of the loam is nearly always too wet when it comes to sterilizing. As for peat and sand, I have seen heaps of these in gardens, parks and nurseries trodden over, growing crops of weeds, mixed with adjacent soil or manure heaps and absolutely sodden. They are *soil slums*. Now, baled or bagged peat is literally sterile when delivered and sand from a pit is uncontaminated. After a short time outdoors, both may be contaminated and, therefore, both may require sterilizing. Lastly, it is impossible to mix wet sand uniformly with loam and peat to make a compost. The soil slum breeds unhealthy plants, bad workmanship and a bad reputation: laxities which horticulture can no longer afford.

Obviously a shed *is* necessary. Where should it be located? How big? Of what design? The answers to these questions call for consideration of the source of the materials used in sterilizing and composting, what is done to them, and where they eventually go.

Location. Loam, peat and sand are the raw materials for compost making. They are bulky, they are heavy, they make large demands on man-power. This is true also of composts. Clearly, to minimize the distance over which compost must be transported, the shed should be erected in a position central to where compost will be wanted, e.g. potting shed, glasshouses. Clearly, too, if loam, peat and sand can be delivered by lorry straight into their respective places in the shed, much labour will be saved. Either the lorry must be able to drive *into* the shed or back *onto* it, at the right positions. Thus, a good approach road is desirable with backing and turning room at the ends and/or sides of the shed.

Size and Shape. The size and shape of a sterilizing and mixing shed will vary from nursery to nursery, according to the particular circumstances. But the same principle should determine size and shape in every case. This principle is that of the production line where, in the process of making or assembling a product, each component is located just where it is wanted in the sequence of operations, thus minimizing the movement of men and materials with a consequent saving in man-power.

Now, what should the order of disposal be in our shed? The loam is the bulkiest of the raw materials, the only one that has to be processed (stacked and sterilized) and the only one that is contaminated before treatment and 'clean' afterwards. Clearly, the raw loam must be dealt with in an area separated

—if only by an imaginary line—from the clean end of the shed. If the imagination can be assisted by some sort of tangible barrier or division, e.g. the sterilizing bins, so much the better. Thus, the first requirement is a shed divided into two areas of convenient size. What size? The answer is: spacious enough to give ample room for dealing with large amounts of soil but not so big as to compel unnecessary walking about or moving of soil. Shape comes into this, too, of course. In general, it is better to err a little on the generous side. Nothing is worse than quarters so cramped that men get in one another's way and sterilized soil is in danger of being brought into contact with unsterilized soil. At this stage, consideration should be given as to what extent the job can be mechanized, since this will bear on the questions of size and shape. The final decisions are tied up with the design of the shed.

Design. By design, I mean the lay-out of the 'production line.' What should it be? The answer lies in the sequence of operations in making composts or, more specifically, what they demand:

Service road.
Loam stacks.
Sieving (shredding) space.
Sterilizing bins.
Peat, sand and fertilizers.
Mixing space.
Storage space (composts).
Glasshouses, etc.

The most logical design incorporating this sequence is given in outline below. It consists of two parallel rows of storage bays separated by a concrete floor or way, along which the soil is moved in the sequence of operations (Fig. 19).

The following points should be noted:

1. The loam should be *stacked* as recommended for John Innes Composts, not merely shot into the loam bay. Consequently the approach to, and design of, this part of the shed should provide for the tipping of the loam off the lorry, either in the shed on the floor next to the bay, or outside the shed next to the bay. In the latter case,

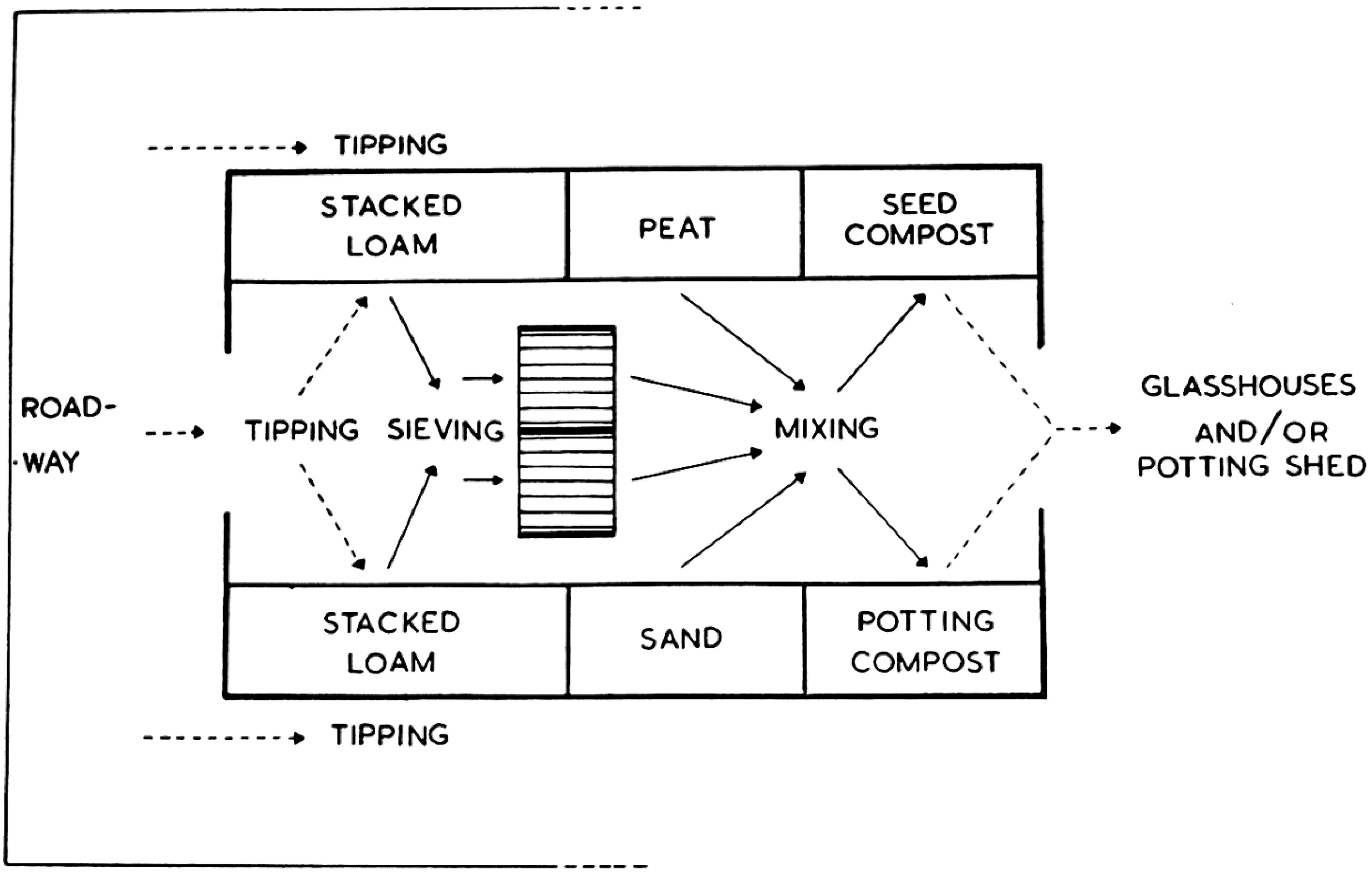

FIG. 19.—Scheme for sterilizing and mixing shed. The shed is a production line along which the materials flow from left to right. A pair of sterilizing bins is in the middle.

removable boards or corrugated iron sheets should form the outer side of the bay to protect the loam stack from rain.

2. Peat, if baled, cannot be tipped. The best that can be done is to unload it as close as possible to the peat bay.
3. Sand is heavy and awkward to shovel. If it can be tipped straight into the bay from outside the shed much work will be saved. *Sand must be kept dry* or good compost mixing will be impossible.
4. The sterilizing bins are raised several inches above floor level (Fig. 16). However, by using a board laid against the high side of the bins a lorry can be driven across them and through the shed if required.

SUMMARY

1. Full details are given for the construction and operation of two bin sterilizers of highest efficiency.

2. In the John Innes Low-Rate Sterilizer steam is generated in a trough of water and 'percolates' through the soil at very low pressure, hence the rate of steaming is low (but efficient). The sterilizer costs £38 to build and will sterilize ½ cu. yd. of soil in 30 to 45 minutes.

3. In the John Innes High-Rate Sterilizer a boiler is used. The rate of steaming is exceptionally high and sterilization is mainly by residual heat after the steam is turned off. Excluding the boiler, the sterilizer costs £14 per bin to build and will sterilize 1 cu. yd. of soil in 15 to 20 minutes.

4. Details are given of other forms of bin sterilizers, i.e. portable, mobile, semi-steaming and baking. The semi-steaming and baking methods are condemned as lacking the precision necessary for modern requirements.

5. The importance of choosing a good and suitable loam for seed and potting composts is emphasized.

6. For protection from the weather, efficiency of sterilization and economical integration with nursery working, bin sterilizers should be accommodated in a shed. Details are given of such a sterilizing and mixing shed designed on the principles of the production line where correct positioning of materials and mechanization of labour enable sterilizing and mixing to be performed with efficiency and economy.

CHAPTER 12

STERILIZING IN GLASSHOUSES: APPARATUS

BOILERS

BOILERS customarily used for the sterilizing of glasshouse soils vary considerably in size and type. The 'high'-pressure (page 30) locomotive boiler on wheels is by far the commonest because most glasshouses are heated by hot water, therefore, a steam boiler must be hired and brought to the nursery. Vertical boilers are almost always fixed, their height precluding transport. Recently, a new type of low-pressure boiler has appeared (page 78) and further developments, long overdue, may be expected. Last, but not least, is the dual-purpose hot-water boiler which can be used for the generating of steam as required. Much greater use should be made of this boiler, especially by the small grower for whom it is specially suitable and economic.

BOILER EFFICIENCY

Efficiency in steaming glasshouse soil begins with the choice of boiler. The two main features to watch are the thermal efficiency of the boiler and its size. Both of these are determined, of course, before ever the boiler is used: it cannot have a higher thermal efficiency or produce more steam than its design and size permit.

In general, the efficiency of the boiler is related to the ratio of heating surface (tubes, etc.) to the grate area; the higher the ratio the greater the efficiency. But the way a boiler is used and maintained by the boilerman also contributes to its efficiency, so we must consider efficiency under two headings: (1) boiler or thermal efficiency, and (2) boilerman or working efficiency.

Boiler efficiency is expressed as a percentage and refers to the amount of heat given out by the boiler compared with that contained in the fuel. However efficient the design of the boiler may be, some heat is inevitably lost up the chimney, in the ashes and as radiation from the external boiler surfaces. This loss is commonly 25 per cent. A loss greater than 25 per cent should not be accepted without question by any business-minded grower. A great deal of fuel would ultimately be saved by the glasshouse industry if growers asked for at least 75 per cent thermal efficiency for their steam sterilizing, and other, boilers.

Boilerman efficiency. If the thermal efficiency of a given boiler is 75 per cent, it by no means follows that in day-to-day working, 75 per cent of the potential energy of the fuel will become available for sterilizing (or heating). The state of repair and cleanliness of the boiler and the state of mind of the boilerman may greatly reduce the amount of steam produced per pound of fuel. I say the state of mind of the boilerman but, to put responsibility where it fairly lies, I should say rather the nursery owner or manager. Horticultural boilers are often grossly neglected and grossly misused, with the result that a 75 per cent potential boiler efficiency is very often reduced to no more than 55 per cent and 40 per cent is by no means unknown. In other words, by far the greatest reform and saving will be made in the use of boiler plant by managers learning to use and treat their boilers in an intelligent fashion. There is no difficulty in doing this. The information has long been available in inexpensive form (17). Only the wrong state of mind stands in the way of much-needed reform. All that I need say now is that every effort should be made to see that doors and dampers fit well and heating surfaces (furnace walls, tubes, etc.) are *frequently* cleaned.

A special word must be said here with respect to boiler cleaning (de-scaling), *vis-à-vis* boiler efficiency. In a closed water circuit, such as the ordinary hot-water system, the same water is heated time and again and practically none is lost and, therefore, none has to be replaced. But in soil sterilization water is continuously evaporated and has to be replaced again and again. Each time a bulk of water is evaporated, the solids in it are deposited in the form of *scale* on the metal surfaces and this scale, because it is a very poor conductor of heat, rapidly reduces the thermal efficiency of the boiler. Therefore, any boiler to be used for steam generation should have an adequate number of inspection (cleaning) points adequately positioned. And the boiler should be de-scaled as a routine matter, by one means or another (page 80). *There are very few districts with water which does not deposit scale.*

BOILER SIZE

For soil sterilization, boiler size is best measured in terms of pounds of water evaporated, or steam produced in one hour* when the boiler is working at full capacity. This depends, as we have seen, on the way the boiler is handled. Good fuel, good stoking and good water supply are essential to getting the full output of steam. It is important to know what this is *in practice.* A convenient method is to work the boiler at full load for ½ to 1 hour and measure the amount of feed-water injected during this period (page 92). Provided the boiler is handled with some efficiency, then the maximum area of glasshouse soil that can be sterilized at any one time for a given size of boiler will be found in Table 10 (page 93). It is assumed that the soil is in suitable condition, i.e. it is dry, loose and well broken up.

BOILER TYPES

Locomotive Boilers. Fixed boilers of this type suitable for sterilizing range in size from about 1,000 to 2,000 lb./hour (100 to 200 gall./hour) and cost from about £1,100 to £1,600. The cost for the corresponding mobile types is about £1,200 to £1,800. Locomotive boilers are usually designed to work at a pressure of 60 to 120 psi. A forced draught unit may be fitted with advantage to a locomotive boiler used for soil sterilization.

Vertical Boilers. Vertical boilers (e.g. dairy sterilizers) range in size from 40 to 140 lb./hour and cross-tube types from 160 to 800 lb./hour. The cross-tube type is not so efficient as the multitubular.

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* Boiler size is sometimes quoted in terms of horsepower. In horticulture this practice is unnecessary, may lead to confusion, and serves no useful purpose (page 160).

Steel Boilers. The dual-purpose horizontal boiler which can be used either as a hot-water or a low-pressure steam boiler (up to 30 psi), ranges in size from 200 to 4,000 lb./hour and costs from £200 to £2,000. Its efficiency is high, especially when there are double-return fire-tubes, and it is readily adaptable to automatic stoking and to oil firing. It has a life of some 20 years.

When used for supplying hot water for glasshouse heating the steel boiler is filled with water and operated in the usual way.

Table 8

ACCESSORIES FOR CONVERTING HOT-WATER BOILER TO STEAM BOILER

	£	s.	d.
Isolating valve	6	0	0
Steam valves (2) to replace water valves on flow and return pipes	11	10	0
Feed-water pump	41	0	0
½ h.p. starter	3	0	0
Float switch	17	0	0
50 gall. tank with ball valve	5	0	0
Pipe-work to pump, etc.	4	0	0
Water gauge	5	0	0
Low-water cut-off device	11	0	0
Steam-pressure gauge	4	0	0
Pressure-stat	12	0	0
Steam safety valve	8	0	0
Blow down cock	2	0	0
1 in. non-return valve		10	0
Float switch and low-water cut-off fittings	10	10	0
	£140	10	0

For the generation of steam, the water level is lowered some inches and the steam collected and piped off at the top of the boiler.

Certain additions to the boiler are necessary for steam generation. These are listed in Table 8. The prices are approximate and refer to accessories for 500 to 1,000 lb. boilers. These additions should be made in full consultation with the boiler manufacturer and a competent engineer.

Mobile Low-Pressure Boiler. In recent years there have appeared in Scandinavia, Holland and Germany, light-weight, low-pressure mobile boilers specifically designed for soil sterilization. There are various models generating steam at pressures between 7 and 45 psi and producing 300 to 1,300 lb. steam/hour. Some are oil fired. The mobility of these light-weight boilers enables them to be taken close to the glasshouses or frame soil to be sterilized, thus doing away with long lengths of steam main. The low steam pressure permits water to be fed direct to the boiler under mains pressure and controlled automatically by a float valve. It remains to be seen whether this type of mobile boiler will be able to compete with the dual-purpose, fixed steel boiler.

We may note in passing that it is possible to use high-pressure boilers, too old to be insured at their original pressure, for low-pressure steaming provided a main of suitable diameter is used.

Hot-Water Boiler with Steam Drum. Occasionally, a grower will fit a steam drum to his hot-water boiler to enable him to use it for soil sterilizing. When a drum is thus fitted, the same accessories mentioned under 'Steel Boilers' must be installed. At one time, the use of a steam drum seemed commendable as an (apparently) inexpensive method of making steam. Further investigation has shown that with the average horticultural boiler in average condition, the installation of a steam drum is not a really satisfactory proposition, especially as insurance difficulties may arise. In the long run, it seems better to plan to get a steel boiler.

BOILER INSURANCE

All boilers working at pressures greater than atmospheric must be inspected, at intervals not greater than 14 months, by a qualified engineer (Boiler Explosion Acts). The best procedure is to insure the boiler with an insurance company specializing in explosion risks. Inspection is then included in the annual premium.

WATER SUPPLY

1. *Water Quality.* The efficiency of a steam boiler is markedly affected by the quality of the water used. If the water is hard, scale is rapidly deposited on boiler tubes, etc., thus

insulating the water from the heat of the fire. Corrosion of the boiler and pipes may also occur. Very hard water should be treated externally by, for example, the lime-soda or base exchange processes (16). Moderately hard water should be treated internally by the addition of chemicals to the feed water. A feed pump should replace the usual injector if the feed water is known to contain sediment.

The above remarks are general in nature and therefore apply to any type of boiler. Sometimes, however, the question of water treatment is determined by the design of the boiler. For example, a steel boiler with narrow water tubes and passages may have a high thermal efficiency and be excellent for hot-water heating. But if such a boiler is used for the dual purpose of heating glasshouses by hot water and for steam sterilizing at sundry times, trouble may be experienced if the water is particularly hard since the tubes cannot be de-scaled mechanically. On the other hand a similar steel boiler with straight fire tubes presents less difficulties if manual de-scaling becomes necessary. Thus, in districts where the water is known to be very hard, careful consideration should be given to the choice of boiler design.

The treatment of boiler water is a highly skilled business, hence, it would always be wise for the grower to consult a water treatment specialist if there is any doubt about the water supply. Treatment is simple and consists in adding chemicals to the feed water. The expense is more than covered by increased thermal efficiency and saving in maintenance repairs.

2. *Feed Water.* An injector or pump is needed to force water into a boiler working at pressure. An injector large enough to meet the full water demand will cause a rapid drop in steam pressure when started up. A better arrangement is to use two injectors, a small one for continuous running and a larger one for meeting peak loads. Such a combination eliminates pressure fluctuations and promotes efficiency.

A steam or electrically driven pump is to be preferred to an injector. It should be large enough to supply water at something like twice the rate at which the boiler evaporates it. In hand-controlled mechanical pumps, ‘a little and often’ is the guiding principle. For stationary boilers a pump with automatic (electric) control is much to be desired. It should be regulated to give a continuous supply at the rate required to keep the water level steady. Incidentally, the exhaust steam from a steam pump can be profitably used to warm the water in the feed tank by means of a coil.

FUEL

1. *Solid Fuel.* The best solid fuel for hand-fired boilers is best Welsh steam coal. Good hard coke can be burnt provided the bars of the fire-box are $\frac{3}{4}$ to 1 in. wide and set $\frac{5}{8}$ to $\frac{3}{4}$ in. apart. Low-grade (high-volatile) fuels can be used by fitting special grates with bars $\frac{1}{8}$ to $\frac{3}{16}$ in. apart together with forced draught but advice on this should be sought from a competent person. If forced draught is not used with low-grade fuels, combustion will be incomplete and fuel wasted unless secondary air is admitted by fitting a special shutter to the fire-box door. The highest thermal efficiency will be obtained from fixed boilers and it is an advantage if these are stoked mechanically, using a washed singles coal. The official war-time ration of fuel for soil sterilization was 40 tons per acre.

2. *Oil.* In the past, oil has rarely been employed for boilers used in soil sterilization. Now that diesel and fuel oil are cheaper, the outstanding advantages of oil firing claim attention, namely, high-efficiency combustion, a constantly bright fire, maximum steam output and minimum labour. On the question of labour, it has recently been established (28) that the cost of handling solid fuel, through all stages from the stockpile to the clearing of the ashes, is about 12s. per ton of fuel for hand-fired or stoker-fed boilers. None of this expenditure arises with oil fuel. Automatic oil burners can be bought ranging from units costing about £100 suitable for boilers rated at 100,000 Btu per hour. The amount of diesel or fuel oil required per acre equivalent to the coal ration, is about 6,000 gall. This figure, however, ignores the increased operating efficiency that could be obtained in many nurseries, say from 55 to 70 per cent. The equivalent quantity of oil then becomes 4,700 galls.

STOKING

1. *Hand Firing.* A poor stoker may put up fuel costs by 20 per cent. More plainly, if fuel is £6 per ton, poor stoking may add £40 or more an acre to the cost of sterilizing. Such wastage is entirely preventable. Good stoking is easily learnt and easily practised (17). The object is to keep as bright a fire as possible all the time. It is not good economy to heap so much fuel on the fire that the stoker is able to occupy himself at length elsewhere between firings. Placing even a small excess of fuel on the fire may cause an undesirable drop in steam output. Good stoking consists in applying fuel thinly and evenly at frequent intervals, e.g. every 5 to 10 minutes, so as to cover the whole of the grate area, paying particular attention to the sides, back and front. Fuel usually burns more rapidly at these points, therefore, more fuel is usually wanted around the edges of the fire than in the centre. Consequently, the fire-bed should be saucer-shaped for greater efficiency. The optimum thickness of the fire-bed varies with the kind and size of fuel. For small fuels it is 2 to 5 in., for steam coal 4 to 8 in. and for hard coke 8 to 10 in. Whatever the thickness of the fire-bed, a primary object in stoking is to prevent thin patches or holes through which cold air rushes into the furnace.

2. *Forced Draught.* A forced draught unit consists of an electric motor driving a fan which blows air evenly *under* the whole of the fire-bed. The motor may be switched on and off by hand or automatically controlled by boiler pressure. Either method gives better results than natural draught, especially in maintaining a steady boiler pressure. The cost of a forced draught unit is £60 to £130, according to size.

3. *Automatic Stoking.* Automatic stokers burning solid fuel can be used only on fixed boilers. Oil firing can be applied to both fixed and mobile(low-pressure) boilers. Automatic firing is a great boon for soil sterilization and should be thought of by growers as the ultimate, but not distant, goal.

STEAM MAINS

The commonest type in use with high- and low-pressure boilers is the 1¼ to 1½ in. mild steel main (1s. 8d. to 2s. 3d./ft.)

with screwed couplings or flanged joints. Only occasionally is 2 in. main seen (3s./ft.). For low-pressure boilers use has been made recently of light alloy pipes with quick couplings as supplied for irrigation purposes. The lightness of the alloy allows sizes of pipe up to 3 in. in diameter (6s./ft.) to be handled with ease and the large diameter permits the flow of low-pressure steam in quantity. A further advantage of light alloy is that it is a poor radiator of heat compared with steel, hence alloy mains have a much lower heat loss than steel. Without doubt, much more will be seen of light alloy mains and quick couplings in the future.

STEAM DRIER AND STEAM TRAP

This combination of instruments is one which no grower can afford to neglect. The function of the steam drier (or water separator) is to separate off from the steam the condensed water that always forms in the main. The steam is led into a metal 'box' where, by means of baffles and the action of gravity (Fig. 20), the heavier water falls to the bottom of the separator to which a steam trap is fitted. The function of the steam trap is to retain the steam whilst permitting the water to escape (Fig. 21). Drier and trap are installed as one unit at the end of the steam main (Figs. 22, 25). It should be noted that *a steam trap alone will not satisfactorily separate water from steam in a sterilizing main*: a drier must be used. If these two instruments are not employed, the condensed water is carried into the soil along with the steam. The wet soil then takes longer to heat and its structure is impaired. Steam trap prices range from £2 to £4.

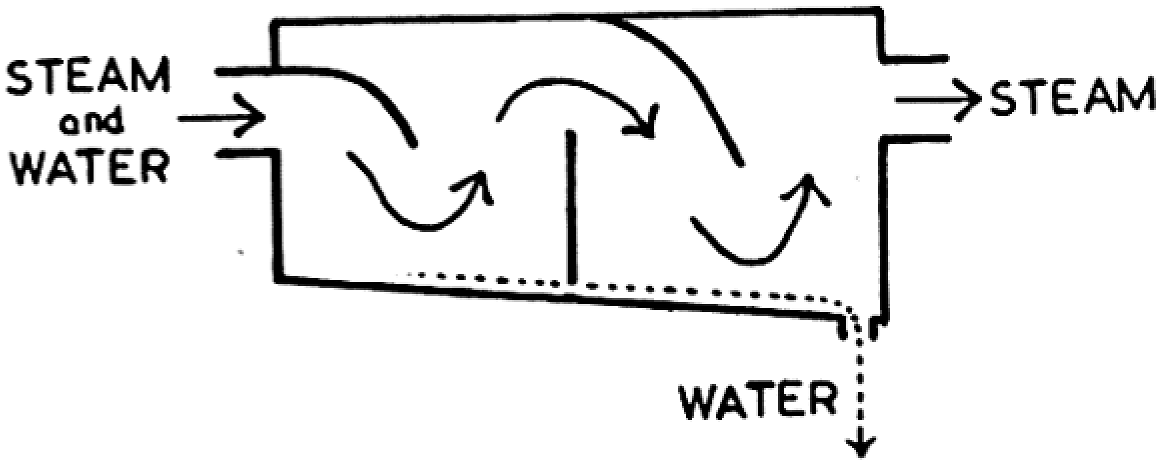

FIG. 20.—Diagrammatic representation of a steam drier (water separator).

It is important that the maximum steam pressure quoted for the trap *exceeds the maximum boiler pressure*, e.g. 30 to 40 psi for low-pressure boilers, 120 psi for high-pressure boilers. Steam drier prices range from £12 for 1½ in. mains to £24 for 3 in. mains.

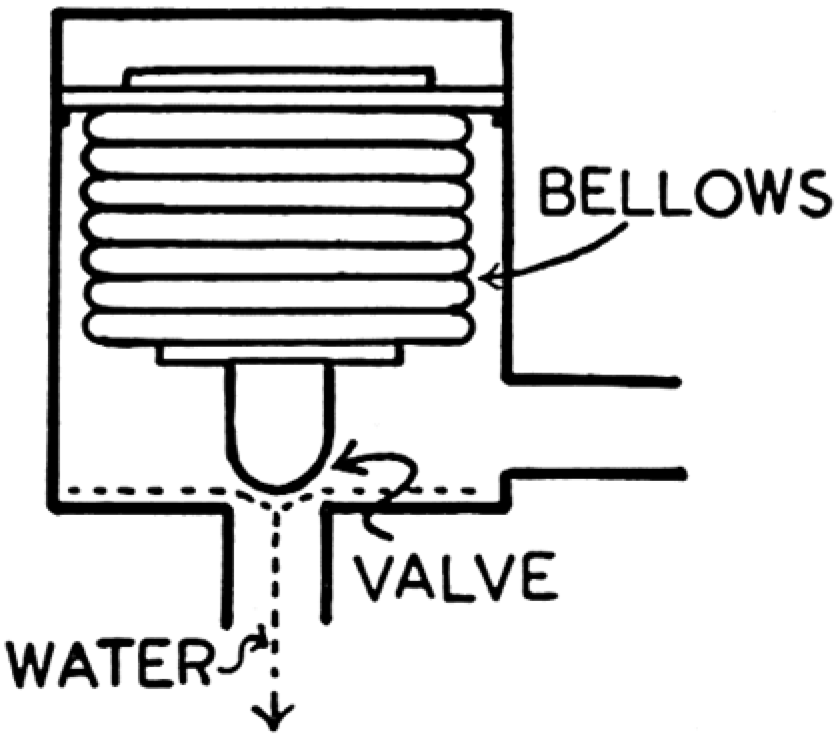

FIG. 21.—Diagram of thermostatic steam trap. The bellows is fixed at the top but is free to expand and contract in the vertical direction. Steam in the horizontal pipe at the bottom expands the bellows thereby closing the valve. When the steam condenses the water accumulates around the bellows and the lower temperature causes the bellows to contract, the valve to open and the water to escape. Immediately fresh steam enters the trap the valve closes again. Thus, steam is trapped but water escapes.

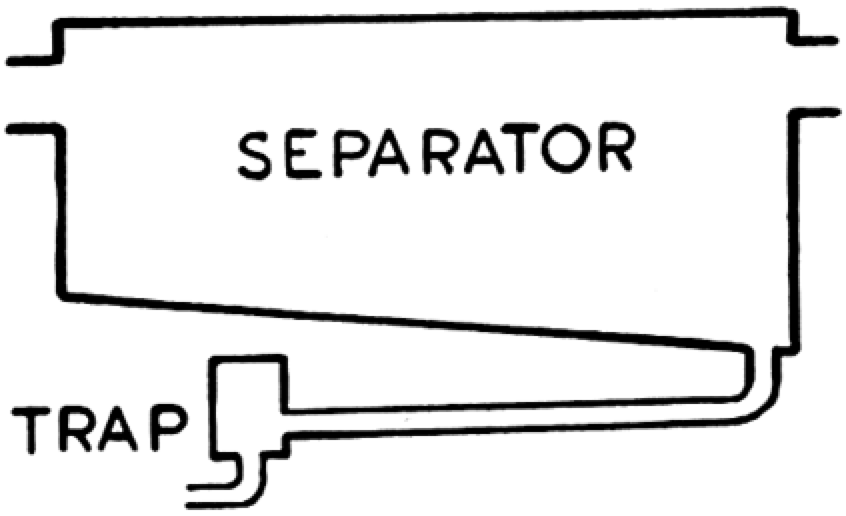

FIG. 22.—Steam drier (water separator) and thermostatic steam trap assembly. A bucket should be used to catch the water from the trap.

PRESSURE-REDUCING VALVE

The use of this device may occasionally be necessary (page 99). It consists of a spring-loaded diaphragm or piston such that the pressure on the outlet side remains constant at a value controlled by the loading on the spring. The loading is adjustable. Thus, a high pressure of 60 psi or more on the inlet side of the valve can be reduced to a low pressure of, say, 5 psi on the outlet side.

INSULATION

1. *Boiler.* Although, to most of us, it may seem incredible that anyone should use an unlagged and unprotected boiler for soil sterilization, nevertheless it happens. And frequently. The heat loss need hardly be measured under such circumstances. It can be felt: yards away. As much as 25 per cent of the fuel may be wasted, totalling hundredweights a day or tons a week. It goes without saying that the greatest economy of all from the use of insulation is to be had by lagging the boiler with a good insulating material, e.g. 85 per cent magnesia compound.

Where the boiler must be used in the open, a shelter, e.g. of corrugated iron, should be used to give protection from wind and rain and thereby reduce fuel consumption. And a good boilerman deserves protection as much as the boiler.

2. *Mains.* The glasshouse grower is not infrequently exhorted by official and other publications to insulate his steam sterilizing mains in order to save fuel. So few growers follow this advice that one might assume they are either wiser than their teachers or more foolish than is credible. Or, of course, just don't care. What are the facts about main insulation? First, the loss of heat by convection and radiation from uninsulated steam main surfaces in still air is of the order given in Table 9. The term 'temperature difference' refers to the difference between the temperature of the main and of the air. A difference of 200° F. applies roughly to low-pressure steam mains (e.g. 15 psi) and a difference of 250° F. to high-pressure mains (e.g. 60 psi). Heat loss will be greater from the portion of the main outside the glasshouse because of the lower air temperature and the cooling effect of wind. However, this loss is not likely to be much higher than 20 per cent of that in still air and, as we shall see, can be ignored.

It will be clear from this table that whether high- or low-pressure mains are used, the fuel saved by insulating with fibre-glass lagging (pre-formed, canvas backed)—the cheapest good insulating material—ranges from 4·4 lb. to 6·2lb./hr./100 ft. of main. With fuel at £6/ton this represents a saving of 2·8d. to 4·0d./hr./100 ft. of main. The cost of fibre-glass lagging is 2s. 8d./ft. run of 1½ in. main and 3s. 9d./ft. run of 3 in. main. For 100 ft. of main the respective costs of the lagging are about £13 for a 1½ in. main and £19 for a 3 in. main.

So much for the general position. Now let us take specific examples. If we accept the 1½ in. main as being of greatest interest in high-pressure steaming and the 3 in. main as being the largest that would be used for low-pressure steaming, we can calculate how many hours mains would have to be used before the cost of the insulating material was recovered. For the 1½ in. main the calculation is £13 divided by 2·8d., or 1,114 hours, and for the 3 in. main £19 divided by 4·0d., or 1,140 hours. Since, steaming 24 hours a day, it takes about two weeks to sterilize an acre of soil, 3 to 3½ acres would have to be steamed before the outlay on insulating any length of main could be recovered.

Table 9

HEAT LOSS FROM STEAM-MAIN SURFACE
(Btu/sq. ft./°F./hr., in still air)

	Difference between pipe and air temperatures		Saving in lb. fuel* per 100 ft. of main. Insulation 85 per cent efficient and boiler efficiency 55 per cent	
Nominal bore (in.)	200° F. Btu loss per 100 ft. of main	250° F. Btu loss per 100 ft. of main	200° F.	250° F.
1¼	25,100	34,700	—	4·5
1½	28,200	38,900	—	5·0
2	34,400	47,800	4·4	6·2
2½	40,800	56,300	5·3	—
3	48,000	67,400	6·2	—

* At 12,000 Btu/lb.

It should be noted that these figures are based on 55 per cent boiler efficiency, i.e. on a basis favourable to the use of insulation. If boiler efficiency is 70 per cent, then the number of hours is 1,418 and 1,451 and the number of acres 4.

This is not all, however. We must make allowance for the rough and tumble of soil sterilization. Insulating material is vulnerable to mechanical damage, which reduces the efficiency of the insulation. Unless the pipes are handled with care and stored in the dry, the life of the insulation will be appreciably reduced. Further, it is to be expected that wider use will be made of lower boiler pressures and alloy irrigation-cum-sterilizing mains. For obvious reasons, dual-purpose mains of this type could not possibly be insulated.

Thus, at first sight it seems as if the grower who dispenses with insulation for his steam mains is not so foolish after all. We must be careful, however. For a second factor that must be considered is the greater amount of condensation in uninsulated as compared with insulated main. Is this of practical consequence? This time, unfortunately, there are so few experimental data that calculations will not help us. Such indications as there are suggest that the extra condensation in uninsulated pipes is of little consequence *if the soil condition is satisfactory*. To put it another way, in the context of this section it is more important to avoid using wet soil than wet steam. *But* soil condition may not always be entirely satisfactory, therefore it is easier and probably less expensive to use a steam drier (page 83) than to insulate the main.

To summarize. Insulation of steam sterilizing mains is worth while for permanent mains and on large nurseries with central steaming plant and long mains. Indeed, there is a good deal in favour of installing a permanent, insulated steam main, say 3 in. diameter, running across the ends or middles of the houses, with a blanked-off point opposite each house. Sub-mains can then be quickly coupled for the steaming of individual houses. Insulation is not worth while* on nurseries with less than 1 acre or so of glass unless steaming is done for several years and the insulating material maintained in first-class condition.

HEADERS

The steam main terminates in a metal distributor or header by means of which the steam is distributed equally through a number of rubber hoses to the steaming pipes. Headers are of two kinds (Fig. 23). The Y-type theoretically gives the most even distribution of steam to the Hoddesdon pipes but can supply steam to two or four pipes only. The cylinder type is the more useful: it can supply steam to any number of pipes from, say, two to ten and in practice gives satisfactory steam distribution. For ease of moving, both types may be mounted on short skids.

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* Please note, we are talking about steam sterilizing mains and not steam *heating* mains.

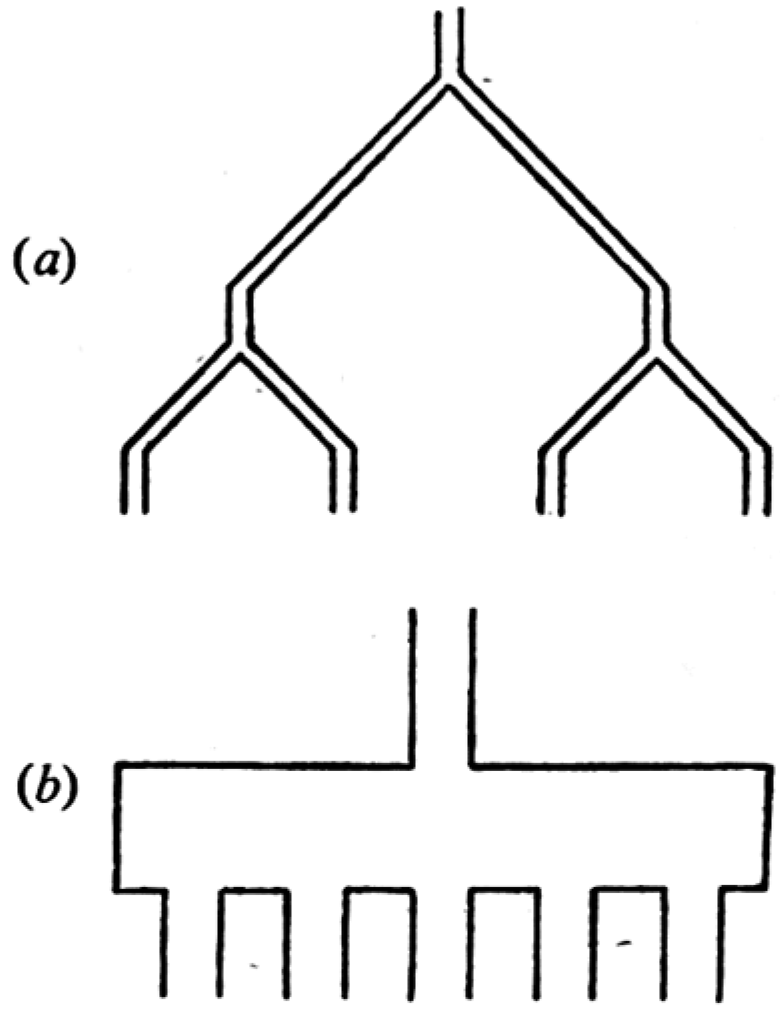

FIG. 23.—Diagrammatic representation of the two types of steam headers (distributors).
(a) Y-header.
(b) cylinder header.

HOSES

Flexible rubber hoses (Fig. 25) are essential to enable rapid connections to be made to the steaming pipes and to give ease and flexibility of movement. Six-ply hose is offered as follows:

1¼ in. dia. 9s. 7d./ft.; 1½ in. dia. 10s. 9d./ft.;
2 in. dia. 16s. 6d./ft.

Push-over hoses, in place of metal couplings, are winning favour.

STEAMING PIPES

These are described in Chapter 13.

SOIL COVERS

Until recently, tarpaulin or canvas have been the only materials available for covering the soil being steamed, (1) to retain steam and thus (2) sterilize the surface. Now, rayon-coated PVC sheeting is being used with some success. It is sold in 26-yard lengths, 39 in. wide, at about 8s. 0d. yard and has been estimated to last for about five seasons.

THERMOMETERS

Many gardeners and growers dispense with thermometers and rely on time: they steam for so many minutes. This is bad practice, if only because the required steaming time may vary from one part of a house to another owing to variation in soil moisture and compaction. Temperature, not time, is the proper criterion in efficient steaming.

Another criticism of the use of thermometers relates to the type of instrument used. Not infrequently this is a long-stemmed thermometer, sheathed in a copper tube, the idea being that it can then with safety be pushed well down into the soil. This is not only unnecessary but unwise. The layer of soil close to the surface is the last to heat up. The surface, therefore, is the danger-spot and it is here that the temperature should be tested. All that is required is a relatively short length chemical type of mercury-in-glass thermometer, costing 7s. to 10s. And all that need be done is to push it *one inch* into the soil, at several places, to make certain all the soil is at a temperature of 212° F.

Better than any thermometer, however, are one's hands: they are more sensitive, they cover a larger area and they can be moved more quickly from one spot to another. And whereas thermometers get broken, hands properly used are indestructible.

SUMMARY

1. *Boiler* (*thermal*) *efficiency* is expressed as a percentage and refers to the amount of heat given out by the boiler compared with that contained in the fuel. It is suggested that an efficiency of not less

than 75 per cent might, in future, be regarded as the acceptable standard.

2. *Boilerman inefficiency* in the operation and maintenance of boilers often leads to a gross wastage of fuel.

3. *Boiler size* is measured in pounds of water evaporated per hour. For efficient sterilization it is necessary to know what this value is *in practice*.

4. *Boilers* used in soil sterilization comprise high- and low-pressure, horizontal and vertical, single-purpose and dual-purpose types. Details are given of each. Special attention is drawn to the merits of the dual-purpose boiler (hot water for heating, steam for sterilizing) for small- to medium-size nurseries.

5. *Water supply*. This should receive more attention than it customarily gets since it is rare for an artificial water supply to be satisfactory. Without water treatment, fuel is wasted and corrosion of the boiler may occur. A specialist should be consulted for advice.

6. *Fuels* are briefly considered and the claims of mechanical stoking and oil firing are emphasized, especially the latter.

7. *Stoking*, if poorly performed, may add 20 per cent to fuel costs. Use of *The Stoker's Manual* will prevent this.

8. *Steam mains*. Steel mains are used with high-pressure boilers. The use of light alloy (irrigation mains) with quick couplings is recommended with low-pressure boilers.

9. *Steam Drier and Steam Trap*. These instruments should *always* be fitted at the end of the main to separate and drain-off condensed water and thus prevent its injection into the soil.

10. *Reducing Valve*. This is an instrument for reducing steam pressure. It is not required when balanced steaming is practised (page 91).

11. *Insulation* of boilers is imperative. Insulation of steam sterilizing mains is worth while on large nurseries and for permanent mains. It is not, as a rule, worth while on small nurseries.

12. *Headers* for distributing the steam to the steaming apparatus are of the Y- and cylinder types. The cylinder type is the most useful since any number of pipes can be used with it.

13. *Hoses* are essential for ease and flexibility of working and provide a connection between the rigid metal steam main and steaming pipes.

14. *Soil covers* are used to retain steam and spread it over the surface of the soil. Tarpaulin and canvas have been used in the past. Rayon-coated PVC sheeting promises to be a useful material.

CHAPTER 13

STERILIZING IN GLASSHOUSES: MODERN METHODS

Balanced Steaming

THIS chapter is one of the most important in the book. It makes clear what very few growers, if any, have appreciated, and it shows what large improvements and economies can be made in the sterilizing of glasshouse soils, in situ.

What has been the general thought and practice in sterilizing soils? It would be fair to say that the great majority of growers imagine they are doing a satisfactory job of work if they have a boiler which generates steam at 'high' pressure, e.g. 80 psi, some mains, hoses and headers and a set or two of Hoddesdon pipes, four pipes to the set. Nothing else is used. Nothing is known about steam pressure in the Hoddesdon pipes. And nothing is understood about the efficiency of the working rate (man-hours) at which the whole job is done. As a result, (1) steam is used wastefully, and (2) the rate of working is determined by the size of a piece of apparatus, viz. the pipe assembly instead of the rate of steam supply.* As we shall now see, the cart is put before the horse; the servant is made master.

What, then, is 'balanced steaming'? I have coined this phrase to express the simplest of ideas. To obtain maximum thermal and working efficiency:

PLOT SIZE MUST BALANCE BOILER SIZE.

This idea is based on the fact previously mentioned (page 32) that the maximum rate at which soil can condense steam efficiently is about 18 lb./sq. ft./hr.

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* Notice these two 'rates.' Rate of steam supply is the measure of the *amount of steam* required to heat a given soil area in a given time. Rate of working is the measure of the *amount of labour* required to treat (dig and steam the soil, move Hoddesdon pipes, etc.) a given soil area in a given time.

Let us see what this means in practice. To obtain maximum thermal and working efficiency using a high- or low-pressure boiler producing 1,500 lb. steam/hr., the size of the plot to be steamed should be 84 sq. ft. (1,500 ÷ 18). To steam this plot eight Hoddesdon pipes* of standard design (page 155) could be used, each 7 ft. long and spaced 18 in. apart. Each pipe will *automatically* pass steam to give the correct injection rate of 18 lb. steam/sq. ft./hr., or 3·1 lb. steam/min./Hoddesdon pipe, without the aid of any further equipment. At this rate, it will be found that the pressure in the standard Hoddesdon pipe is 2 psi. In other words, a pressure of 2 psi (whatever the length of Hoddesdon pipe) indicates that the injection rate is correct.

This is a very useful figure to remember because, whereas growers cannot measure steam flow in sterilizing equipment, they can readily measure steam pressure by way of a check. If the pressure is found to be greater than 2 psi in a standard Hoddesdon pipe, then more steam is being injected into the soil than it can condense efficiently and steam and fuel will be wasted. Thus, it is essential that a pressure of 2 psi is not exceeded.

What must be done to achieve balanced steaming? Very little. The first step is to ascertain what plot size is required to take the full output of steam from the boiler. This can be seen from Table 10. It should not be assumed that the boiler gives its full rated output. A test should be made by running the boiler at full load and measuring the amount of feed-water supplied in ½ to 1 hour. This must be done carefully. The level of the water in the water gauge must be the same before and after the test and the water taken up should be *measured* in gallons, not calculated.

The second step is to decide the best dimensions for a set of pipes to suit the particular nursery. A pipe spacing of 18 in. may be taken as standard for the great majority of cases. So, referring again to the 1,500 lb. boiler which steams 84 sq. ft. of soil, the total length of Hoddesdon pipe will be 56 ft. This can be arranged as a set of four 14 ft. pipes, or eight 7 ft., or any other combination that adds up to 56. Thus, any length, breadth or shape of house or border can be dealt with without restricting steam supply. When the number of pipes per set is two or four, the Y-type of header (Fig. 23a) can be used to connect the steam main to the Hoddesdon pipes. With numbers greater than four, a cylindrical header is a necessity (Fig. 23b). It should be noted that the longer the Hoddesdon pipes, the fewer pipes and hoses will be required per unit area of soil.

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* The use of the Hoddesdon method has been cited throughout this chapter because it is more widely used than any other in Britain. Nevertheless, the principle of balanced steaming applies equally to other methods.

Table 10

RECOMMENDED PLOT SIZE AND LENGTH OF HODDESDON PIPE, FOR A RANGE OF BOILER SIZES. BASED ON A STEAM INJECTION RATE OF 18 LB./SQ. FT./HR.

Boiler size (evaporating capacity) lb. steam/hr.*	Recommended plot size (steaming area) sq. ft.	Total length of Hoddesdon pipes, spaced 18 in. apart†
200	11	7 ft.
400	22	14 ft.
600	33	21 ft.
800	44	28 ft.
1000	56	35 ft.
1500	84	56 ft.
2000	112	70 ft.

* Divide figures by 10 to get water consumption per hour (gallons).

† If the pipes are spaced at less than 18 in., a greater total length will be required.

The third step is to buy a steam-pressure gauge measuring 0 to 10 psi and costing £2 to £3. This is inserted on the top of the riser of one of the Hoddesdon pipes. A riser is chosen in preference to a header since the distance of a header from the Hoddesdon pipes may vary from nursery to nursery, hence header pressure will also vary and cannot be standardized. Once the pressure in the Hoddesdon pipe has been ascertained the gauge can be removed to avoid damage to it. The gauge is used *to make certain* that steam pressure does not exceed 2 psi. It does not matter if it is as low as 1 lb.

I have now outlined the requirements for balanced steaming. It is very clear, however, from conversations I have had with growers, advisers and research workers, that appreciation or even practice of balanced steaming by no means removes the widespread and deep-seated misconceptions about the effects of pressure in steam sterilization. Probably, the best way of clearing up this confusion is to give the questions asked by enquirers and answer them.

Let us see what we can learn. For the sake of simplicity I have, throughout the answers, referred to a 1,500 lb. boiler and Hoddesdon pipes. Other sizes of boiler and other apparatus could have been quoted just as pertinently. Purely theoretical and unimportant factors have been omitted in the answers, which relate to practice only.

Question: You say pressure in the Hoddesdon pipes should be 2 psi. Won't it vary according to the length of the steam main, i.e. it will be highest when I am sterilizing close to the boiler and lowest when I am sterilizing in the glasshouse farthest away?

Answer: No. The correct number of pipes to use for a boiler producing 1,500 lb. steam/hr. is eight (Table 10). If we assume an even distribution of steam between these pipes then each will pass $\frac{1{,}500}{60 \times 8} = 3{\cdot}125$ lb. steam/min. and this quantity can only be passed when the steam is at a pressure of about 2 psi in the Hoddesdon pipe. Therefore, if the boiler output is constant, so too must be the pressure in the Hoddesdon pipe. If the pressure is greater than this, then more steam is being produced by the boiler. Remember, we balanced the rate of steam injection against the *full boiler output* so fluctuations will generally be in a downward direction. Thus, the rate of steam injection can never exceed the recommended maximum rate.

Question: Does this mean, then, that length and size of main have no effect?

Answer: Neither length nor diameter of main will affect the principle of balanced steaming. What will happen is that if the main is of small diameter and/or very long, the frictional resistance to the flow of steam will be greater and more pressure will be required at the boiler end to force the full boiler output through the main against this resistance. I have dealt with the question of main size in Chapter 7.

Question: My boiler is hand fired and I notice that when I put fuel on the fire or when I use the water injector, the boiler pressure falls (i.e. boiler *output* drops), obviously because the fire is not so hot in the one case and the water has been cooled in the second. Won't this affect pressure in the Hoddesdon pipe?

Answer: When it is stated by the maker that a boiler has a certain evaporating capacity or when a grower measures the capacity of that boiler, it is on the basis of a bright, hot fire, probably as hot as it is ever likely to be in normal day to day working. When, therefore, a grower balances plot size against boiler output he does so on the average *maximum* output of the boiler. Hence, fluctuations in boiler pressure and output are almost invariably in the downward direction, e.g. when fuel is put on the fire, when feed water is put in the boiler.

For instance, let us suppose that you have (1) a 1,500 lb. boiler, with a pressure range up to 120 psi, which you use at a pressure of 60 psi, and (2) eight 7 ft. standard Hoddesdon pipes delivering 3·1 lb steam/min. at 2 psi, in each Hoddesdon pipe spaced 18 in. apart. In other words, you are practising balanced steaming and supplying steam to the soil at the correct rate of 18 lb./hr./sq. ft. soil surface.

Now, you notice that as a result of stoking and water intake the boiler pressure falls to 40 psi which indicates, of course, that there is a fall in steam output. We will suppose this is now as little as 1,000 lb./hr. *Experiment* has shown that the flow of steam in each Hoddesdon pipe will now be 2·07 lb./min. with a pressure of 0·9 psi and a rate of injection of 12 lb./hr. (i.e. two-thirds of the previous rate). *But experiment* has also shown that when the rate falls from 18 to 12 lb./hr., the efficiency of steam injection is not reduced.

Thus, the range of fluctuation in boiler pressure and output normally occurring in practice is of no consequence with balanced steaming since a low, but adequate, steaming rate is automatically ensured.

Question: You have just mentioned (hypothetically) the boiler pressure dropping from 60 to 40 psi. Since it takes 60 psi to work a water injector reliably, what do I do?

Answer: When you practise balanced steaming using a high-pressure boiler, boiler pressure may fall below 60 psi for two reasons, the first of which I have just mentioned. The second one is this. When balanced steaming is done very close to a high-pressure boiler, e.g. 30 ft., the boiler pressure (remember, not the output) may fall below that needed to work a water injector. In this event, all that has to be done is partially to shut down the boiler valve until there is just enough pressure to work the injector reliably. Thereafter, in the large majority of cases, the valve need not be touched again and balanced steaming will go on as before, whatever the length of main. If a pump is used in place of an injector, then no such adjustment to the boiler valve may be necessary, as most steam pumps will work down to a pressure of 25 psi.

Question: I am not sure that I follow your argument about partially closing the boiler valve. You say I should do this when I am steaming at the nearest point to the boiler and thus raise the boiler pressure just high enough to work the water injector. Now as I move farther and farther away from the boiler, adding to the length of the main and the frictional resistance it offers, won't this require a rather high pressure in the boiler?

Answer: It will require a *higher* pressure, but nothing at all out of the ordinary. After all, you are using a boiler made to generate steam between 60 and 120 psi, so if the pressure rises from, say, 60 to 80 psi this is only what the boiler was intended to do.

Question: Yes—I think I've got the idea. It rarely matters whether the resistance offered by the valve is greater than that offered by the main, or vice versa. Provided my steaming is balanced, boiler pressure adjusts itself automatically and balances out valve and main resistance, so full output of steam goes on without interruption?

Answer: Exactly! There's more than one balance to balanced steaming. Remember, however, that building up boiler pressure to work the injector applies only to high-pressure boilers. Low-pressure boilers don't have injectors but mechanical pumps which work independently of boiler pressure.

Question: You say that for steaming to be thermally efficient, the pressure in the Hoddesdon pipe must be low. I believe some people use a pressure-reducing valve at the end of the main. Then they can ignore fluctuating pressure due to the brightness of the fire, cold feed water, etc.: the reducing valve gives a uniformly low pressure at the header.

Answer: That is true. But while low pipe pressure gives the highest *thermal* efficiency, it does not alone automatically ensure high *working* efficiency. For example, suppose your boiler is giving a full output of steam and the Hoddesdon pipe pressure is 6 to 8 psi (a common figure as steaming is done at present), then a reducing valve will enable you to achieve a constant low pipe pressure of 2 psi. But steam supply will now be restricted* by the reducing valve, exactly as if it were a partly closed cock, with the result that it will take you longer to steam a given area of soil. You can only overcome this disadvantage by increasing the plot size, i.e. by resorting to balanced steaming. Thus, a reducing valve alone is not a satisfactory solution. Indeed, if in the above example it were used to bring the Hoddesdon pipe pressure down from 6 to 8 psi to 2 psi, the fire would have to be reduced to avoid blowing off steam at the boiler.

Question: You mention Hoddesdon pipes. Now, I notice that in the course of a year or two, the $\frac{1}{8}$ in. holes increase in size because of wear and rusting. How does this affect balanced steaming?

Answer: It doesn't. All that happens is that the pressure in the Hoddesdon pipes drops below 2 psi, but the full steam injection rate will go on as before (provided the plot size is not altered).

Question: I heard of a case recently where a small grower got a contractor to do his steaming for him and the contractor brought along a 2,000 lb. boiler. Now, if balanced steaming were practised, the plot size would have to be 112 sq. ft. Wouldn't it be impossible to sterilize such a large plot in a house only 15 ft. wide and wouldn't a reducing valve help?

Answer: Well, let's consider the matter. We could make the steaming plot width half that of the house, i.e. $7\frac{1}{2}$ ft. The length of the plot would then be $112 \div 7\frac{1}{2}$ or 15 ft. Two men are always required for any reasonable sized plot when Hoddesdon pipes are being used and the two men could easily pull back pipes 15 ft. long. Five pipes, each 15 ft. long, would do the job without a reducing valve. A cylinder header would be required for five pipes. As I said in my previous answer, if a reducing valve were employed with the idea of steaming a smaller plot, the full output of the boiler could not possibly be used and the fire would have to be kept low to avoid blowing off steam. So, you see, in a case of this kind a reducing valve might be said to make complications, not solve them.

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* Since it is *quantity* of steam that is wanted, the term 'restricting valve' would be much more to the point when the steaming is *un*balanced.

Question: But I know of several growers who have installed reducing valves and have proved that by doing so fuel has been saved.

Answer: Of course. If your steaming is not balanced and you introduce a reducing valve you will cut down the rate of steam injection and therefore save fuel. But in doing so you will have put up the working time and so more money will have to be spent on labour. If, however, your steaming is balanced, you will not only be making the same saving on fuel, but keeping working time and labour costs down to a minimum.

Question: About that contractor. If everyone does balanced steaming—and bearing in mind the many different sizes of glasshouses—won't contractors (and growers) find they want too many different lengths of Hoddesdon pipe to be convenient?

Answer: At first glance that seems a possibility, but only because of the lack of standardization in every direction. It is beyond doubt that more and more standardization *must* come, for economic reasons. An inevitable result of research, of new and accurate knowledge about plant production under glass, is that modifications must be made in nursery organization and practice. This will take time: no magic can suddenly alter things. Only a plan of development can do that. Every grower and contractor can, from time to time, work out for himself the developments required to meet the ever-changing conditions. After all, Hoddesdon pipes are cheap enough relative to the whole cost of steam sterilization; and considered as a part of the requirements of modern sterilizing as set out in this chapter, buying new pipes is an investment that will pay very good dividends.

Question: What about very large boilers generating 7,000 to 10,000 lb. steam/hr.? Could these be used for balanced steaming?

Answer: No. Nor by any other means either, in ordinary glasshouse practice. The amount of steam *must* be reduced at source if the size of plot is to fit the average size of house. This can be done by using a suitable cock near the boiler or by using a suitably sized sterilizing main to take a reduced steam supply from the boiler. Alternatively, a reducing valve can be used as a method of restricting steam supply.

Question: Then is a reducing valve ever necessary?

Answer: Yes. It is needed in exceptional cases, e.g. when high-pressure steam is employed for heating the glasshouses and at the same time low-pressure steam must be taken off for soil sterilization.

Question: I appreciate the point that when I have too high a steam pressure in the Hoddesdon pipes, therefore too few pipes, much of the steam escapes from the soil, is wasted, hence fuel is wasted, too. Now, if I adopt balanced steaming and use more pipes to reduce the rate of supply of steam to the soil, shall I not also slow up the rate of working and, therefore, lose on the roundabouts what I have gained on the swings?

Answer: Not at all. The rate of steaming is slower, but the area steamed is larger and the two balance. *Balanced steaming is the only way of combining high thermal efficiency with minimum labour costs. It is the fundamental necessity, whatever apparatus is used. All else is of secondary importance.*

Before we go on to consider the different kinds of apparatus used in steam sterilizing, let us take a backward look at the way we have come. For now we can put together the various factors concerning steaming apparatus that make for the highest efficiency in the steaming of glasshouse soil. Here they are:

1. A boiler of high thermal efficiency.
2. Oil firing > automatic stoking > hand stoking, in order of sustained efficiency.
3. A trained boilerman.
4. A lagged boiler.
5. Steam mains and hoses of adequate diameter.
6. A steam drier and trap.
7. A steam-pressure gauge.
8. The correct soil area, i.e. total length of Hoddesdon pipe.

To these matters concerning steaming apparatus, we can add the matters concerning soil condition (Chap. 8). The soil should be:

1. Dry.
2. Broken up to a good, deep tilth.
3. Loose.
4. Covered during and *after* steaming.

METHODS OF STERILIZING

Four methods of sterilizing glasshouse soils are in use in Britain at present, viz. Hoddesdon, Grid, Harrow and Tray methods. Of these, the Hoddesdon method is by far the most widely used. Variations in the dimensions of the component parts of the four types of apparatus and in their use are common. These variations are arbitrary and sometimes even capricious.

From any point of view this state of affairs is unsatisfactory. It is also unnecessary. The whole of the requirements for sterilizing glasshouse soils can be dealt with efficiently by two systems, the Hoddesdon method and what I have called the Comb method. Further, for ordinary purposes, there is no need for variation in the dimensions of component parts of sterilizing apparatus. Standardization can now be recommended and this I have done for both Hoddesdon and Comb methods.

HODDESDON METHOD

For general purposes in Britain, the Hoddesdon system has hitherto been considered to be the most efficient, adaptable and labour-saving. Any number of pipes can be used, in any length up to 14 ft. or so without impairing steaming efficiency; they can be spaced as desired at any depth; they are easy to move. A typical Hoddesdon pipe (Fig. 24) is made of iron, has an inside diameter of 1¼ in. and during steaming lies horizontally in the soil. One end is closed with an iron plug. The other end is fitted with an elbow 2 ft. long which rises vertically above the soil and then turns at right angles to end in a coupling joint. The underside of the horizontal pipe is perforated from

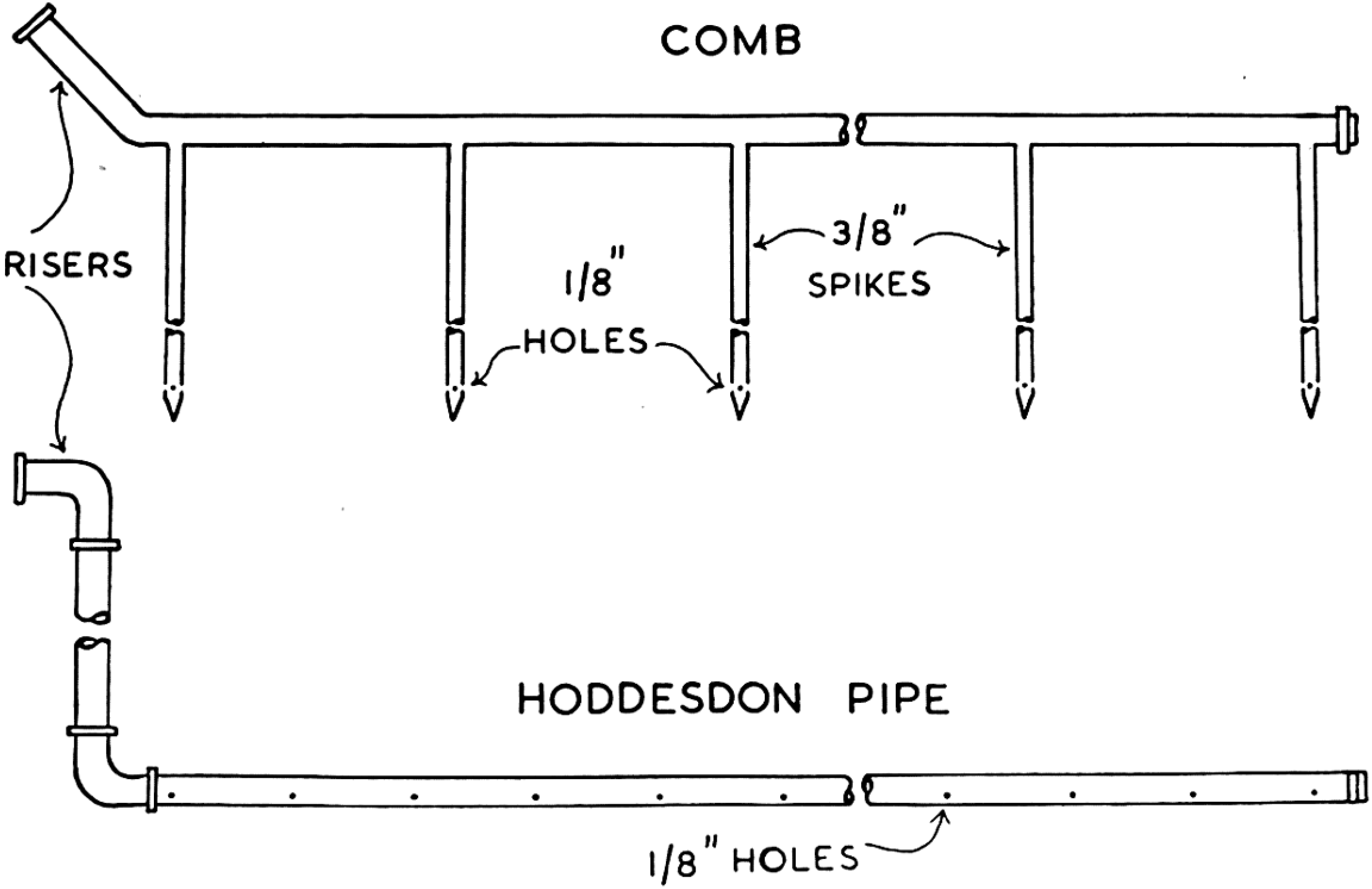


FIG. 24.—Diagram showing chief features of Comb and Hoddesdon pipes. Spikes 15 in. long. Holes in Hoddesdon pipe 5 in. apart.

elbow to plug with ⅛ in. holes spaced 5 in. apart, in two staggered rows, one on either side. The first hole is placed close to the elbow and the last hole close to the plug. In so far as the dimensions of the house permit, long Hoddesdon pipes should be used, e.g. two pipes each 14 ft. long rather than four 7 ft. long, as there are then fewer connections to make and there are fewer overlaps (page 106) between the steamed plots along the length of the house.

A set of pipes is made up by connecting each one of the requisite number to a common header by means of a flexible hose, 5 to 6 ft. long (Fig. 25). This header in turn is connected to the end of the steam main by some 20 ft. of flexible hose. Thus, starting from the boiler, the assembly consists of boiler, steam main, steam drier and trap, long steam hose, header, short steam hoses and Hoddesdon pipes. Any number of sets can be used at once by employing additional headers.

It is *essential* that the distribution of the steam from the main through the headers to the Hoddesdon pipes should be equal at all points, i.e. pipes and bends must be the same in number, size and length.

The theoretical principles governing the size and spacing of Hoddesdon pipes have been stated (14) as follows: (1) to avoid undue drop in steam pressure along the pipe, its cross-sectional area should be 1½ to 2 times the total area of the holes; (2) the spacing of pipes should not exceed the depth to which they are buried by more than 25 per cent; (3) Hoddesdon pipes up to 9 ft. long should be of 1 in. diameter. For longer lengths the diameter should be 1¼ in. Practical considerations, however, suggest that simplification can be achieved without any loss of efficiency. Thus, there is no reason why Hoddesdon pipe diameter should not be standardized at 1¼ in. and the spacing of the pipes at 18 in. so long as the soil is not unduly wet. Full-scale experiments have shown that this spacing is quite satisfactory under average conditions.

Using Hoddesdon Pipes

A common method of working is to use two (or more) sets of pipes side by side, steaming first with one set and then with

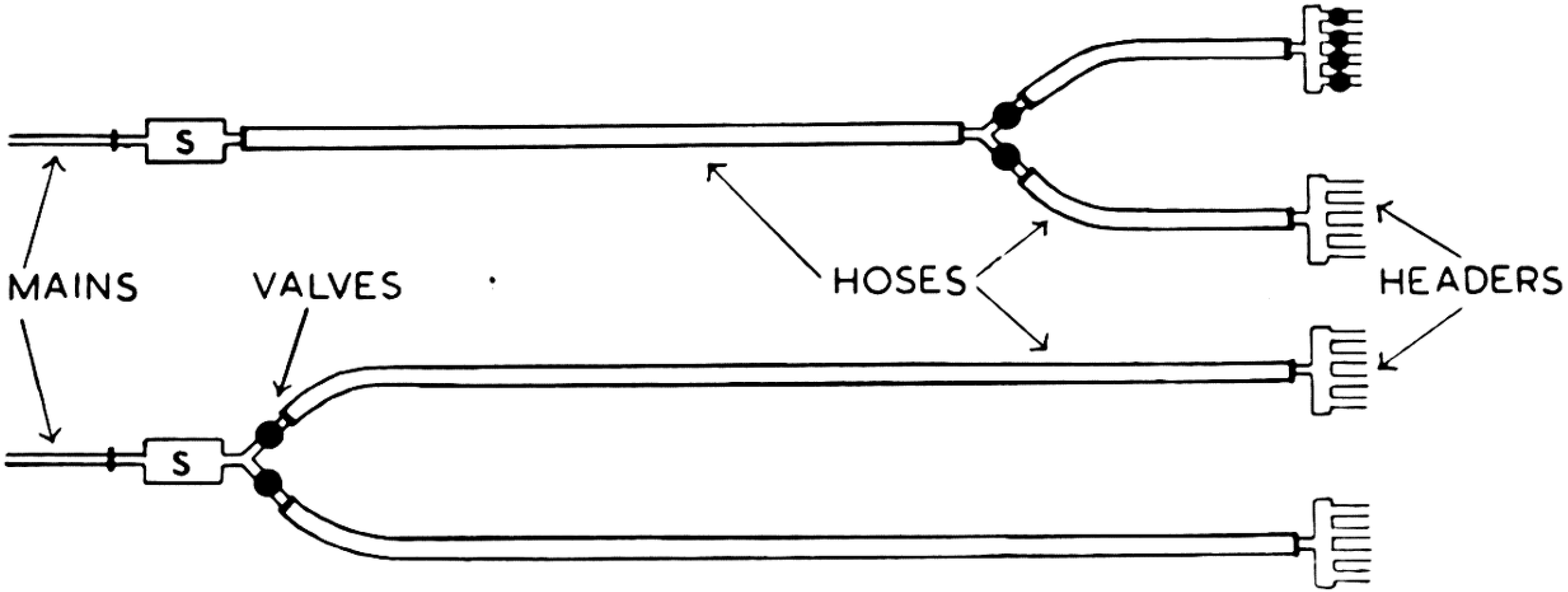


FIG. 25.—Two methods of using long hose-pipes (short ones connect the headers to the steaming pipes).

Above: Total length shortest, valves close to workers but hose under pressure when valve closed.

Below: Total length of hose longest, valves distant from workers, no pressure in hose when valves closed, maximum flexibility of operation.

S = Steam drier and trap.

the other. In this way a strip is treated, two sets wide, from one end of the house to the other. For efficiency of steaming and convenience of working, careful consideration must be given to the length and number of pipes per set and to the number of sets that fit the width of the house.

We start with the boiler: its size determines the total length of Hoddesdon pipes which can be used each time. With a 1,500 lb. boiler and 18 in. between pipes, the total length of pipe is 56 ft. which may be divided into four pipes 14 ft. long, five 11 ft. long, six 9 ft. long, seven 8 ft. long or eight 7 ft. long, the longer pipes for preference.

The next consideration is the depth at which the pipes should be placed. When pests or diseases are not prevalent the practice of 'fertility steaming' can be followed; indeed, most sterilizing of glasshouse soils is in this category. In fertility steaming the pipes are placed about 12 in. deep. By forking up the bottom of the trench the soil will be sterilized to a further depth of 6 in. or so. If the bottom is left unforked and compacted only a further inch will be sterilized. Forking the trench, therefore, is a sound practice.

Finally we come to the width of the houses. Suppose this is 28 ft. Then 28 ft. divided by 18 in. equals $18\frac{2}{3}$, an awkward number. If we call it 20 it will not matter and 20 is exactly divisible by 4 or 5. Thus, a set of pipes could comprise four pipes 14 ft. long, or five 11 ft. long. And five sets of four pipes or four sets of five pipes will fit nicely into the 28 ft. width of the house at a little less than 18 in. apart.

And here a digression will not be out of place. As more and more scientific information becomes available, so standardization becomes not only easier but the more desirable. Thus, the width (and design) of a tomato house should be determined by the lay-out of the plants (cf. Guernsey system), the number of heating pipes, the requirements of soil sterilization, and so on. All of these and similar factors deserve careful thought before building a house. The glove should be made to fit the hand; the other way round is not only uncomfortable but uneconomic!

The detailed procedure in using Hoddesdon pipes is as follows:

1. Dig a trench of the required width and depth close to the side wall of the house and running its full length. For 'fertility' steaming when there is little disease present, a depth of 12 in. may be considered adequate. At the other extreme, if the soil is heavily contaminated with pests or disease the depth of the trench should be increased to 18 in. Take the soil to where steaming will finish, for the filling up of the final trench.
2. Fork up, to a depth of at least 6 in., the bottom of the first length of trench which is to be sterilized, leaving the soil as loose and open as possible. Break down all lumps to a size not greater than 1½ in. diameter. In doing this, avoid re-compacting the soil; the object is to leave air spaces in the subsoil into which the steam can readily penetrate.
3. Place a single Hoddesdon pipe as close as possible to the foundations of the wall. Keep the pipe quite level. Tread in as few places as possible while putting the pipe in place.
4. Take out a similar trench parallel to the first and joining it. Throw the soil loosely over the pipe in the first trench until it is full, keeping the surface quite level. Fork up the bottom of the new trench and lay the second pipe the required distance from the first. Cover with soil taken from the third trench.
5. Continue this process until all the pipes comprising the first set have been laid in position *plus* the first pipe of the second set. The odd pipe belonging to the next set to be used is always placed in position to obviate the use of boards to keep the soil from falling into the trench. Cover the surface of the soil with canvas or PVC sheets. These should be twice the length of the plot so that one half covers the plot previously steamed and one half the plot being steamed.
6. Connect the steam hoses to the first set of Hoddesdon pipes (but not the odd pipe) and turn the steam on. See that the pressure at the Hoddesdon pipe *does not exceed 2 lb.* Continue steaming until the surface layer of soil reaches 212° F. Check the rise in temperature (page 89)

at several points, especially *mid-way* between the pipes and *on the surface.*

7. As soon as all the fine soil has reached a temperature of 212° F. turn off the steam valve. *Leave the covers in place* during the whole of the time the next plot is being steamed. This is most important. It is the only way of making sure that all the *surface* soil is sterilized. The last spots to heat up are always surface spots. The surface temperature of uncovered soil may fall as much as 40° F. in 4 minutes but as little as 10° F. when it is covered (page 89), i.e. well on the safe side.
8. While steaming is in progress with the first set of pipes, prepare the rest of the second set by digging them in, one by one, alongside the others. As soon as steaming is finished with the first set disconnect the steam hoses, connect them to the second set of pipes, turn the steam on and proceed as before.
9. Pull back the first set of pipes, using gloves or cloths to protect the hands from the hot metal. One man can pull back a 7 ft. pipe, but a 14 ft. pipe requires two men. Start with the pipe having the long open trench behind it. Pull this pipe straight back by means of the vertical portion sticking out of the soil. Leave 6 in. of the horizontal portion in the sterilized soil to ensure overlapping of the work. Repeat the process with the other pipes, one by one.

Current costs of sterilizing per acre are given as:

	£
Labour, 960 hours	144
Fuel, 35 tons	175
Feedwater treatment, repairs, depreciation and insurance	110
	£429

No factual information is available respecting either average boiler, stoking and steaming efficiencies or the range of these efficiencies. However, from observation of average nursery practice it is certain that the overall efficiency of soil sterilization is no more than moderate. The difficulty is to put a figure to it and at the same time estimate, for the grower's guidance, the degree of improvement that can reasonably be expected. Believing that phrases such as 'a considerable saving' or 'more economic' are the bane of much advice offered in the past, I prefer to try to estimate, on the basis of such experimental evidence as we have, the *order* (size) of improvement the average grower may expect by adopting efficient methods. The figures are given below and are deliberate underestimations. They are based on steaming with pipes 12 in. deep (18 in. sterilizing depth) and 18 in. apart.

	Fuel saved per acre (per cent)
Boiler and boilerman efficiency	15
Trickle steaming	20
Balanced steaming, soil moisture and tilth .	30

Let me repeat. The figures provide an *indication* of the degree of economy that may be expected. They imply that a saving in fuel of £100 per acre would be possible on some nurseries. Often there will also be a saving in labour.

Where strip-sterilizing of glasshouse soil, as done in Guernsey, is a safe practice, the total area to be steamed can be reduced by 40 per cent with an accompanying reduction in costs.

GRID METHOD

The traditional Grid apparatus is an assembly of pipes similar to that used in bin sterilizing, except that the header is usually only 1 in. diameter. The branches may be two to six in number, 3 to 4 ft. long and spaced 9 to 15 in. apart. The branches are perforated on the underside with $\frac{1}{8}$ in. holes as in a Hoddesdon pipe. Welded into the middle of the header is a vertical 1 in. pipe with a screw connection at the top for the steam hose. A grid with more than six branches is difficult to move. And the soil has to be thrown farther than with Hoddesdon pipes.

Using Grids

The method of using grids is similar to that with Hoddesdon pipes, as follows:

1. Take out a trench to the necessary depth and width across the end of the house. Place the excavated soil near the site of the final trench. Fork up the bottom of the trench.
2. Place one or more grids in position side by side. Cover with soil from a second trench made immediately behind the first. Cover the soil with a tarpaulin large enough to cover two plots and begin steaming.
3. Place a second set of grids alongside the first. When the first area has been steamed, connect the steam hoses to the second set of grids and steam this area in turn.
4. While the second set of grids is being used, attach two hooks to the header of the first grid in the first set and pull it back into the prepared trench. Pull back the other grids in turn. Leave the end 6 in. of the grid branches in the sterilized soil to ensure overlapping of the work.
5. Cover the grids in the second trench with soil from a third trench. And so on.

The above brief description of the Grid method has been given to enable comparison to be made with the Hoddesdon method. The fact is, no case can be made for using the Grid method for steaming glasshouse soil. It has not a single advantage over the Hoddesdon or Comb methods; on the contrary, the Grid method has inherent disadvantages. The logical conclusion, therefore, is to consign it to the limbo of practices that have had their day. Horticulture can no longer afford the 'luxury' (euphemism for foolishness) of utilizing second-rate methods or apparatus.

TRAY METHOD

Shallow, metal trays are inverted on the surface of the soil. Steam is introduced beneath them and gradually penetrates into the soil. The trays are cumbersome to handle and the steam penetrates only a few inches, especially on heavy soils. The Tray method is quite out of date for general purposes.

SPIKE HARROW METHOD

The traditional 'Harrow' apparatus has a horizontal back or framework of 1¼ in. iron pipes, 4 ft. long and 3 ft. wide. Into this a number of ⅜ in. pipes or spikes are welded at right angles. The spikes are usually 12 to 15 in. long, spaced 7 in. apart along the harrow and 12 in. apart across it. Each spike has a ⅛ in. hole about 1 in. from its far end for the emergence of steam. A metal tray is fixed over the back to conserve steam which is supplied to the harrow by means of a curved pipe.

This apparatus is both heavy and awkward and it is difficult for the two men required to move it to avoid stepping on the treated soil. Better results with much greater convenience can be obtained by using long, single pipes with spikes. Such a unit no longer resembles a farm harrow; therefore, I propose to call it a *Comb* (Fig. 24).

Table 11

SUGGESTED STANDARD DIMENSIONS FOR COMBS

Pipe		Spikes				Combs
Length	Internal diameter	Length	Internal diameter	Spacing on pipe	Holes (⅛ in.) per spike	Distance apart in ground
Up to 14–15 ft.	1¼ in.	15 in.	⅜ in.	12 in.	4	18 in.

COMB METHOD

The back of the comb is a 1¼ in. pipe as used in the Hoddesdon apparatus and the teeth hollow spikes as used in the Harrow apparatus. Combs have been used by a few growers but there have been no fixed standards. Therefore, the details in Table 11 are now put forward as standard for the Comb apparatus and method.

The spikes are closed at the lower end and pointed to facilitate penetration of the soil. The holes are drilled about 1 in. from the pointed end at equal distances apart in the horizontal plane (Fig. 24). One man can handle a comb up to 10 ft. in length; two men are required for greater lengths. A pair of wooden handles should be fixed about 3 ft. apart near the middle of a one-man comb, i.e. at the point of balance which, on account of the weight of the riser, will be nearer the front of the comb than the back. For the longer two-man units a handle should be fixed at each end.

As in the Hoddesdon method, steam is supplied to the comb by means of a flexible hose coupled to a riser at one end of the horizontal pipe, the other end of which is closed.

Using the Combs

1. Use a two-wheeled plough with subsoiler to break up the soil to a depth of 12 to 15 in. Where ploughing is impracticable rotary cultivate the soil deeply by going over it twice.
2. Push the combs into the soil until the horizontal pipes rest on the surface. With a fork settle the soil snugly around the spikes to minimize loss of steam.
3. Cover the soil with *strips* of double-length material, a little wider than the distance separating the pipes and laid between them so as to overlap them an inch or two.
4. Connect up hoses and steam as for Hoddesdon pipes.
5. Turn off steam, withdraw combs (which can be lifted out without removing the covering or stepping on the sterilized soil) and move *backward* to the next positions.
6. Drag covers over the new plot, without uncovering the old one.
7. Proceed as before, down the length of the house as in the Hoddesdon method.

To achieve balanced steaming, combs should be used in the same way as standard Hoddesdon pipes. For example, using a 1,500 lb. boiler, the plot size is 84 sq. ft. and the number of combs required at a spacing of 18 in. is eight 7 ft. long, or four 14 ft. long, etc.

DRAIN TILE METHOD

In the methods of glasshouse steaming so far described, the sterilizing apparatus is brought to the glasshouses, assembled, used, dismantled and then put away until the next time it is wanted. All of which involves much labour, particularly with the Hoddesdon method so widely practised in Britain.

This is in distinct contrast to practice in the U.S.A. where permanent (20 to 30 years) buried 'tile,' as they are called, merely have to be connected to the steam main whenever sterilizing is to be done and an acre of soil sterilized in a day or two. In other words, the methods used in Britain entail low capital outlay but high running costs whereas in America the capital outlay is high but running costs are very low.

The details which follow are based on the American practice of steaming a large area, slowly, for 1 to 3 hours but boiler size, plot size and steam requirements have been adjusted to conform to the experimental findings described in this book, also to British glasshouse practice.

Either 3 or 4 in. tile (land drains) may be used. The 4 in. size is said to be less subject to displacement by cultivation than the 3 in., owing to the much larger tile surface in contact with the soil. The larger joint area of the 4 in. tile is claimed to be another advantage of this size in that it gives better distribution of steam to the soil. The house is divided into plots such that each plot comprises a single transverse header supplying steam laterally to the tile lines (Fig. 26). The shape of the plot is not important. Its length and breadth should not exceed 50 ft. and 30 ft. respectively, or steam distribution may be unsatisfactory. In planning the lay-out of the plot, the tile lines should be 18 in. apart from centre to centre, and at a depth of 18 in. from the soil surface to trench bottom.

The header (Fig. 27) is made of 2 to 3 in. diameter galvanized steel or wrought iron pipe and is closed at one end. At the other end an elbow and riser are fitted to carry the pipe above soil level for connection to the steam main. The upper end of the riser is provided with a cap to exclude soil when not in use. Holes are drilled on opposite sides of the header at 18 in. intervals and $\frac{3}{8}$ in. pipes, 6 in. long, welded on. The function of these short pipes, or 'nipples,' as they have been called, is to carry steam into the end of the tile lines. A patented header tile is used in U.S.A., consisting of an ordinary tile, one end of which is blocked except for a small hole through which the nipple is pushed (Fig. 28). The function of the header tile is to make a good connection between header pipe and tile lines and prevent excessive loss of steam. On the other hand, the soil in the vicinity of the header is the least likely to be properly sterilized, therefore, ¼ in. holes about a foot apart are sometimes drilled in the header itself to ensure adequate steaming. It saves labour to have the risers grouped in pairs to facilitate connection to the steam main. It is an advantage to connect the ends of the tile lines together as shown in Fig. 29. Then, should a blockage occur in a particular line, the steam can enter from the other side of the blockage and sterilization is assured.

Hand digging the trenches, using a line and spade, is probably the most economical method in the average-size British glasshouse. The soil removed from one trench is placed directly into the one previously dug. The bottom of the trench may be made level; slope is not essential since condensation can easily find its way out through the tile joints. If the ground itself slopes then, of course, the trench bottom should follow the slope.

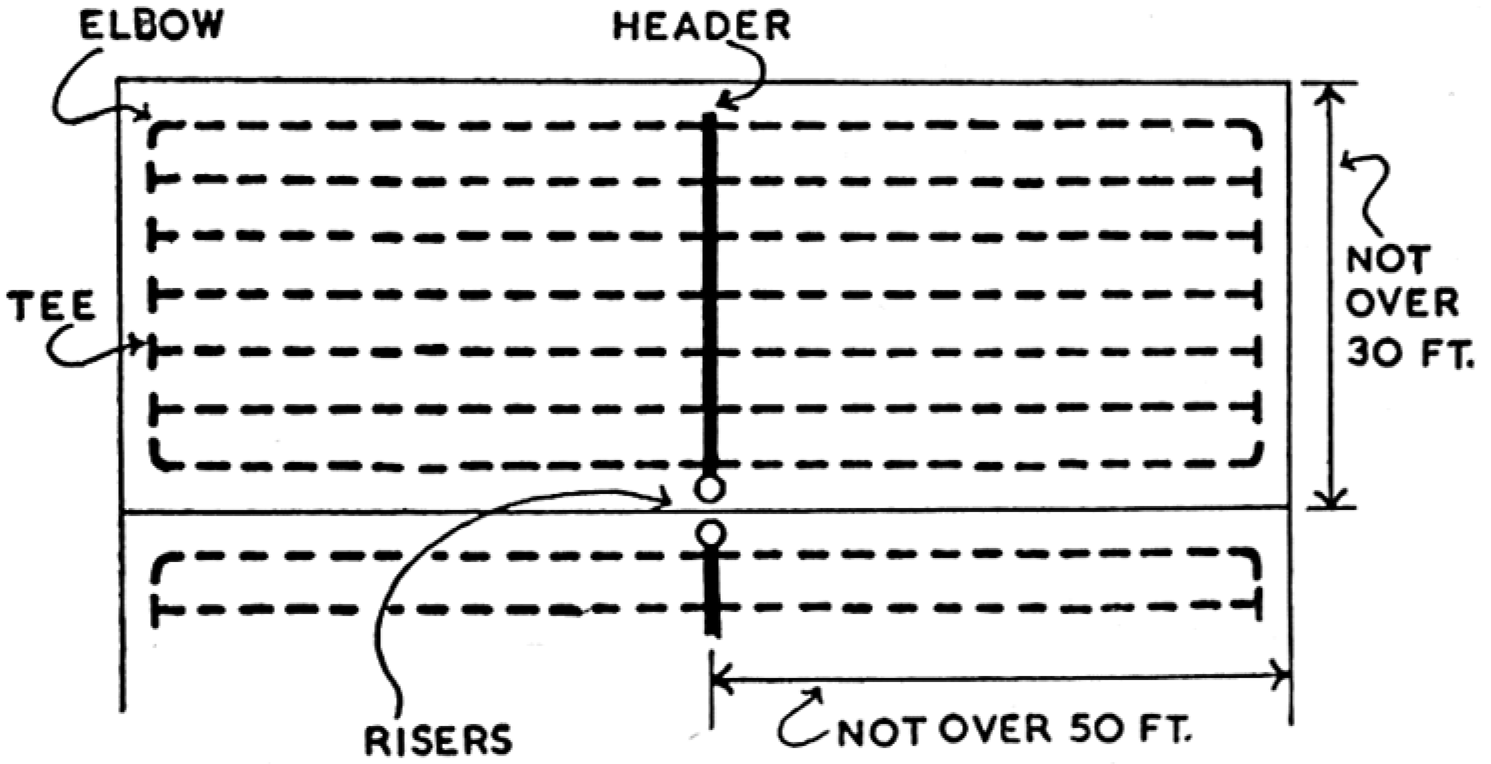


FIG. 29.—Schematic representation of buried Drain Tile method of soil sterilization (not to scale) as practised in U.S.A.

Using the Tile Method

Before steaming begins cover the plot with a sheet of PVC, or 1 in. of peat. It takes 1 to 3 hours to steam thoroughly. Test the top inch of soil with a thermometer. When the temperature has reached approximately 212° F. turn the steam off and leave the soil covered for a further 30 minutes. Uncouple the steam main and proceed to sterilize the next plot. Don't screw on the riser cap until the soil has cooled, otherwise con-

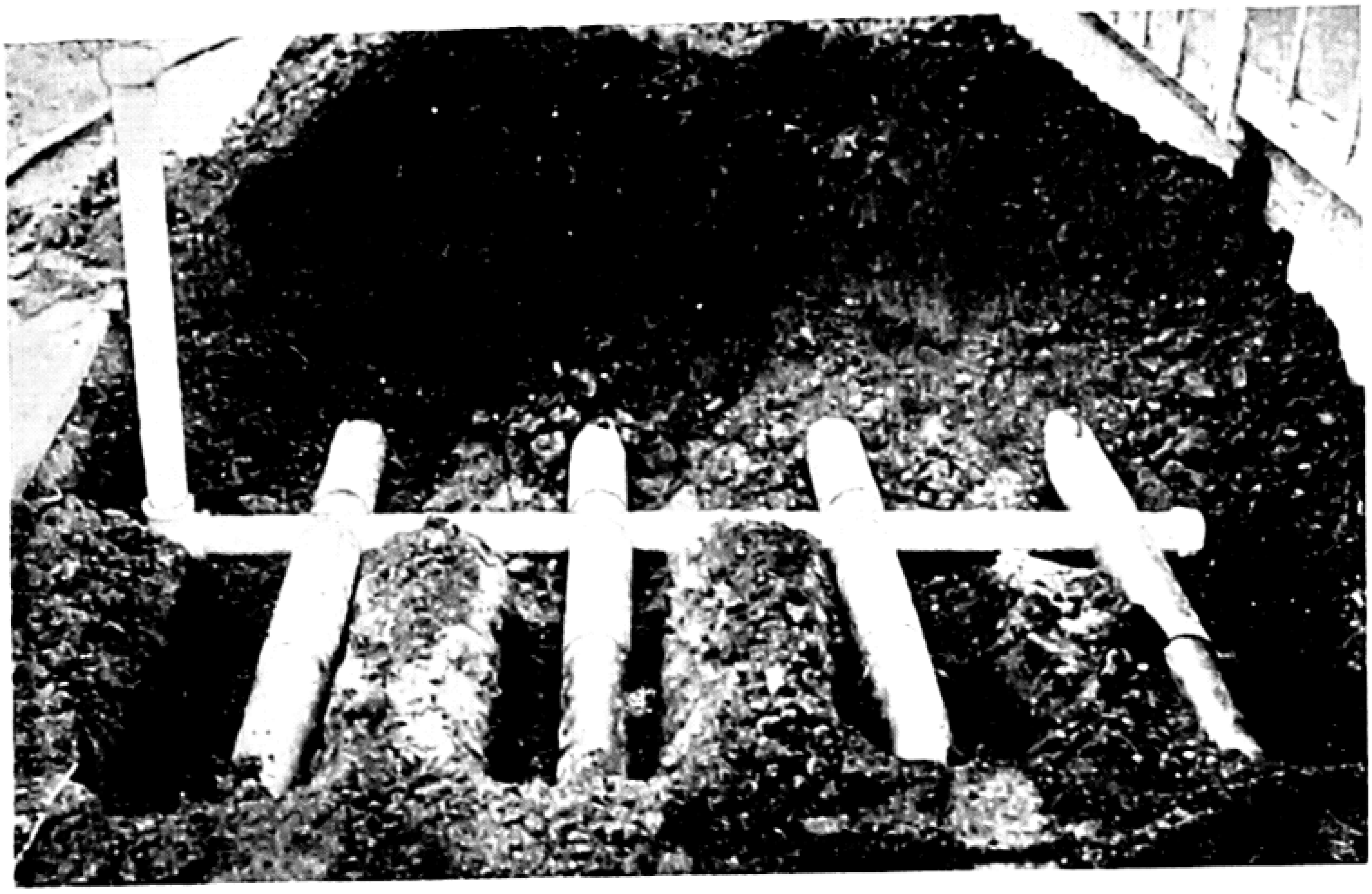


FIG. 26.—The permanently buried Drain Tile method of steaming glasshouse soil, showing iron header with capped riser and four lateral tile lines on each side of the header.

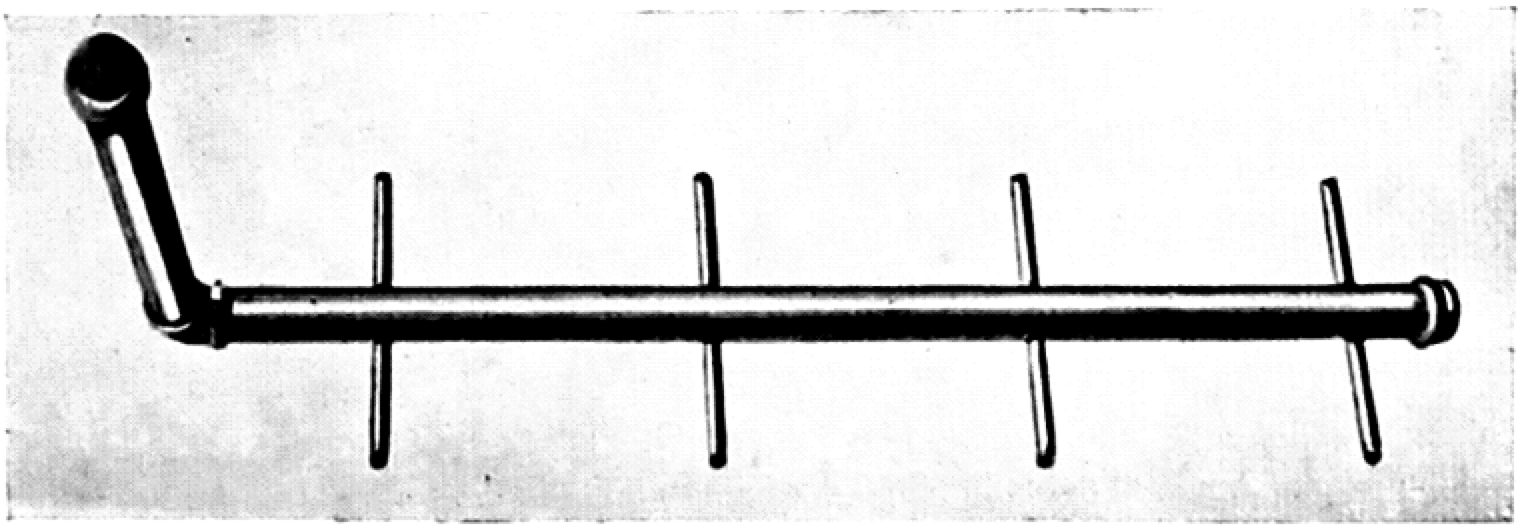


FIG. 27.—Iron header for use in Drain Tile method of soil sterilization. The short lateral pipes or 'nipples' feed steam to the tile lines.

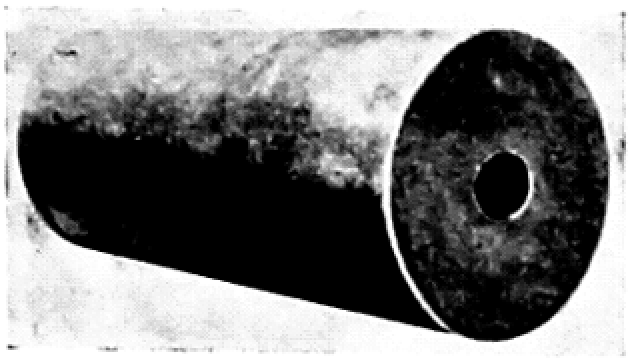


FIG. 28.—Patent 'header tile.' These are pushed over the nipples on the header to minimize loss of steam.

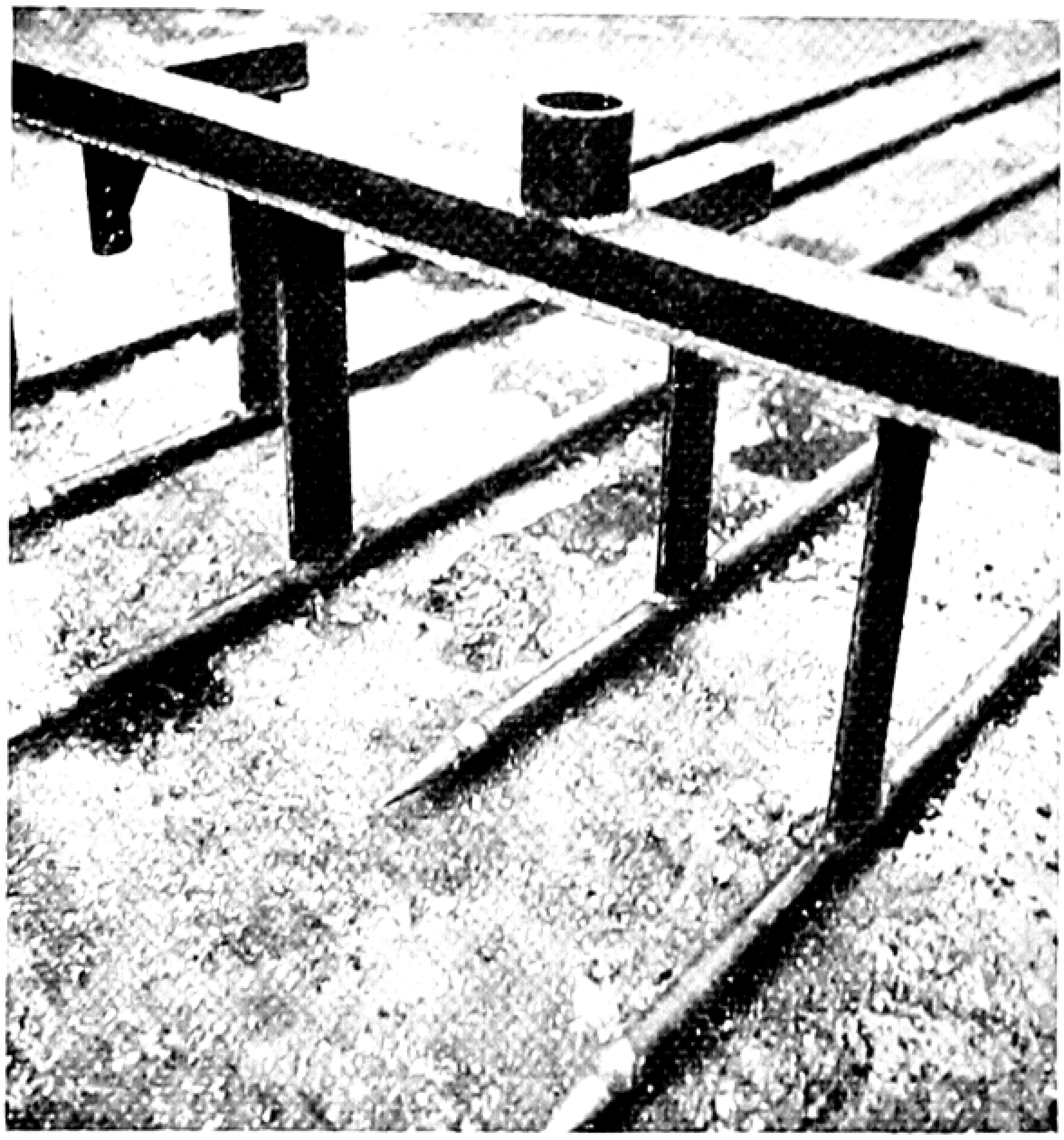
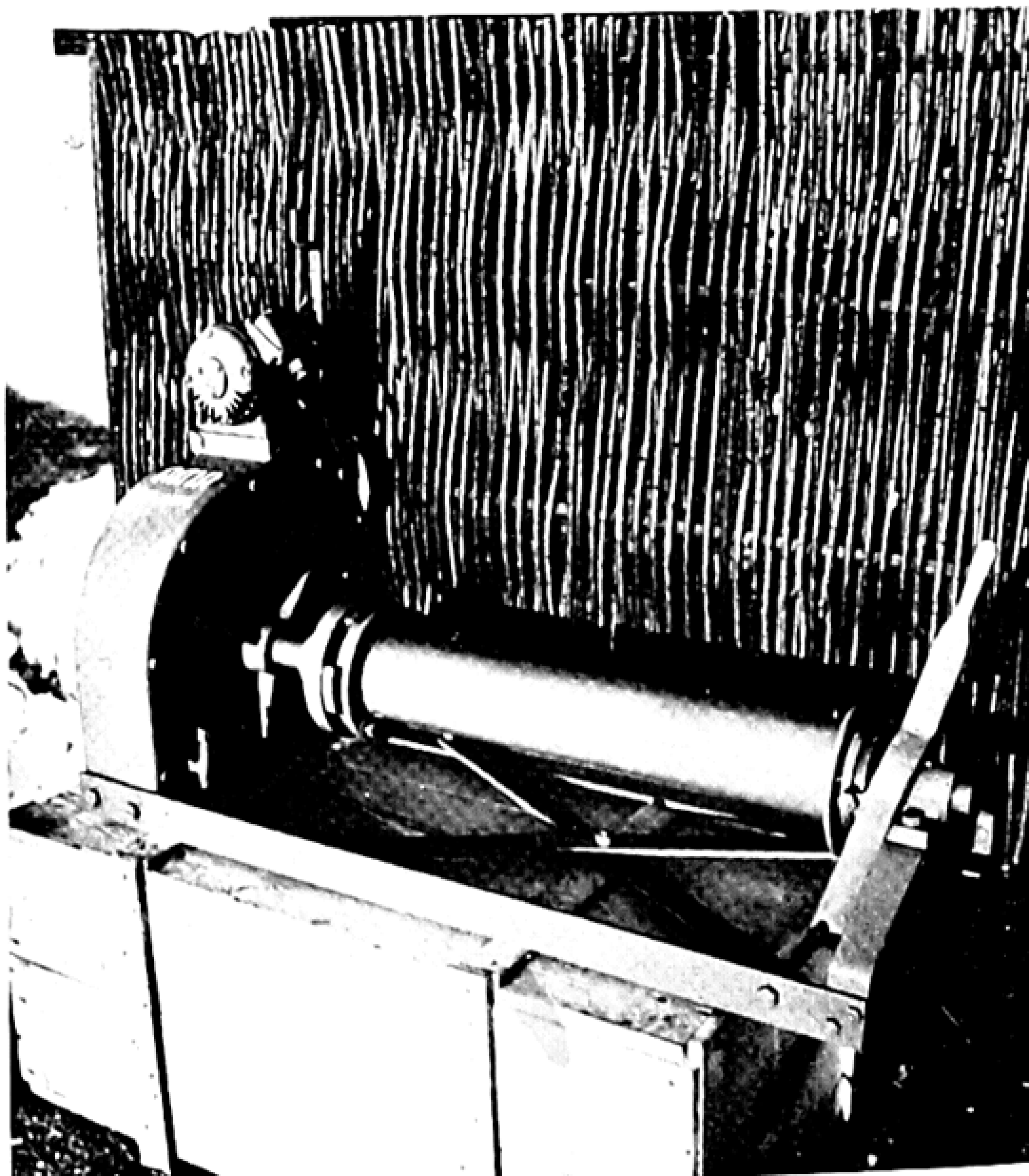


FIG. 31.—A steaming plough.

FIG. 32.—Electric winch for hauling steaming plough.



densation of the steam inside the tile will create a partial vacuum in the tile and draw in soil through the joints, clogging them.

It is stated (18) that (1) the average fuel consumption in the buried tile system is about 2 lb. coal/sq. ft. of sterilized plot or 39 tons per acre; (2) increase in moisture content of the sterilized soil is from 2 to 4 per cent of the dry weight of the soil; (3) old, organic glasshouse soils benefit by leaching after steaming, one heavy leaching being preferable to several light leachings at intervals; (4) manure should be added before sterilizing.

We now come to an important question for British growers. How does the Drain Tile method compare with the Hoddesdon and Comb methods? We will assume that (1) a 1,500 lb. boiler is the size most commonly used in Britain, (2) the drain pipes are spaced 18 in. apart and buried 18 in. deep, (3) the soil is in excellent condition and, therefore, requires no more than 6 lb. steam/cu. ft. of soil for thorough sterilization, and (4) the steaming period is 2 hours.

The amount of steam required per acre is $43{,}560 \times 1\frac{1}{2} \times 6 =$ 392,040 lb. The boiler generates 1,500 lb. steam/hr., therefore, the total steaming time per acre is about 260 hours. It should be noted that, in theory, the Hoddesdon method should take the same time under the same conditions, i.e. the saving using drain tile is in labour, not in time.

Next we must consider plot size. Steaming takes 2 hours, therefore, 3,000 lb. steam is available in this time. Each square foot of soil surface is equivalent to $1\frac{1}{2}$ cu. ft. of soil requiring 9 lb. steam. Therefore, $3{,}000 \div 9 = 333$ sq. ft. (if a steaming time of 3 hours is proposed, the plot size becomes 500 sq. ft.). With a house 150 ft. × 30 ft., the plot size could be 30 ft. × 11 ft. or 15 ft. × 22 ft. and the headers and pipes arranged accordingly.

Finally, there is the question of costs. The price of 3 in. and 4 in. drain pipes (tile) is approximately £16 and £19 per 1,000 respectively. The cost of hand digging the trenches, back-filling and laying the pipes is estimated as £400 per acre. If the whole of the ground is double-dug to a depth of 18 in. and the pipes laid as digging proceeds, the cost is estimated at £600 per acre.

Thus, the lowest cost will be when 3 in. pipes are laid in trenches and the total cost per acre will be:

	£
30,000 3 in. pipes @ £16 per 1,000 . .	480
Digging 30,000 ft. of trench and laying pipes	400
	£880

If the cost of labour using the Hoddesdon method is reckoned as £150 per acre and the hire of the boiler, etc., at £70 per acre, then it seems that the total cost of installing drain tile could be recovered in four steamings. This comparison, of course, is the most favourable for the Drain Tile method. Before coming to final conclusions, growers should compare the cost of the Comb and Steaming Plough methods (page 119).

It should be noted that the Drain Tile method could be adapted to the strip sterilizing of soil in tomato houses planted in the Guernsey manner. Furthermore, pre-planting warming of the soil in tomato houses could be readily done using permanently buried tile.

BENCHES

Wide use is made in the U.S.A. of soil 6 in. or so deep, on benches, for the propagation of plants, a practice rarely seen in this country. Much labour is saved if bench soil is sterilized in situ, hence some attention has been given to the matter.

For bench sterilization, the buried perforated pipe (cf. Hoddesdon pipes) and buried tile methods have been used in much the same way as for beds. A fourth method of bench sterilizing is claimed to be superior to the others and is commonly practised (19). It consists of covering the bench with steam-tight rubberized cloth, kraft building paper, or plastic sheet, temporarily fastened over the entire bench (Fig. 30). Steam, at a boiler pressure of 5 to 15 psi, is led along the length of the bench by means of a single line of pipes or tile laid on the *surface* of the soil and is forced into the soil by the covering. For benches up to 20 ft. long no piping may be necessary. Sheet-

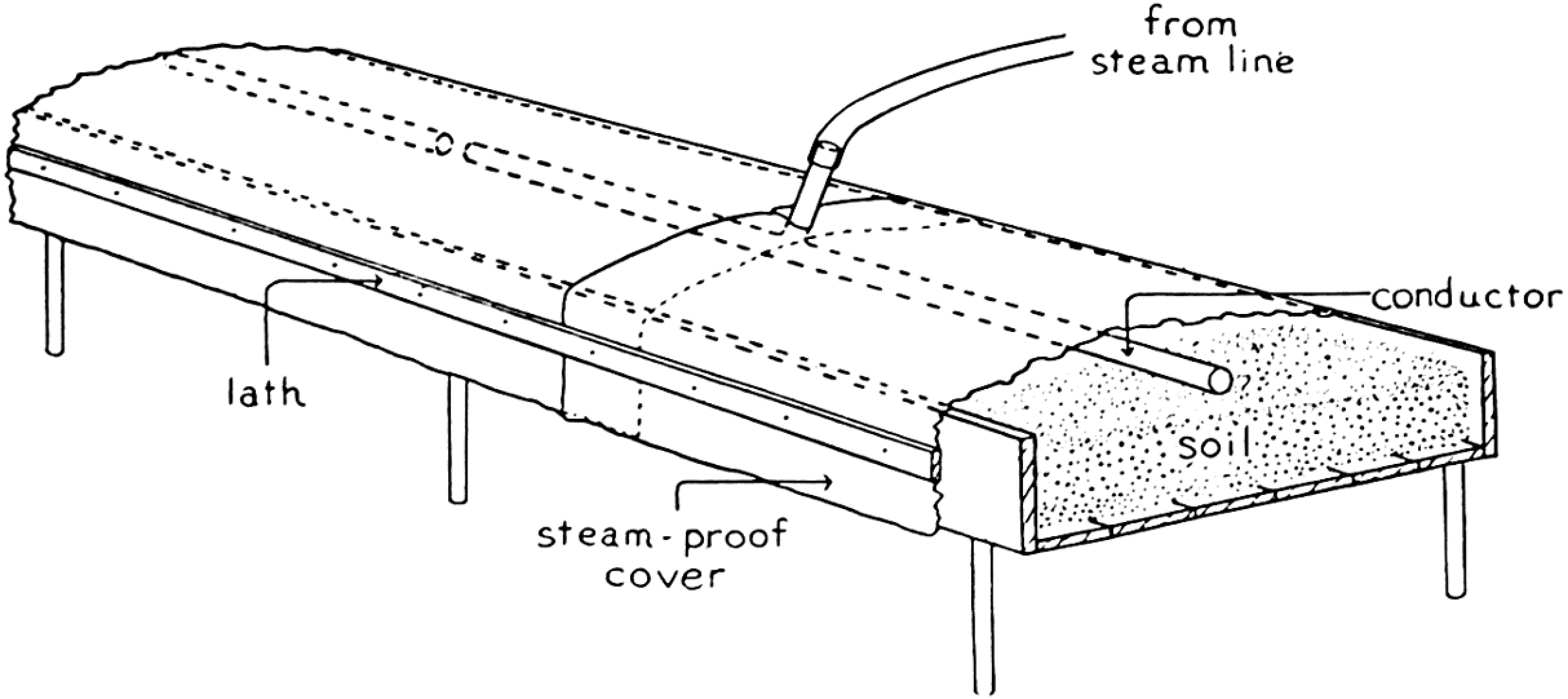


FIG. 30.—Showing the use of a surface pipe (conductor) and steam-proof cover to sterilize soil on a bench.

metal down-spout, cut into 4 to 10 ft. lengths spaced ½ to 3 in. apart between ends, is a cheap steam conductor which has been found to give rapid distribution of steam to all parts of the bench. Canvas hose, through the fabric of which the steam escapes uniformly, has also proved a lightweight, durable and easily handled material.

The covering material should be strong enough to withstand some steam pressure. On wooden benches the covering is best secured by bringing it down at least 4 in. over both sides of the bench and holding it in place with wooden laths (strips) nailed to the sides. On concrete benches where laths cannot be used, angle-iron may be laid along the edge of the bench to hold down the covering. Sufficient slack should be allowed to permit the covering to bellow 5 or 6 in. from the soil in the middle of the bench when the steam is turned on. Laths laid across the pipe at intervals assist in rapid distribution of the steam.

Steam should be turned on gradually so as not to blow off the cover or crack the bench if it is made of concrete. It is recommended in U.S.A. that the steam be turned off when the temperature of all the soil is 180° F. and the cover is left on for a further 30 minutes and then removed to allow the steam to escape and thus avoid undue condensation.

Raised Beds

Very often carnations and sometimes tomatoes are grown in Britain in raised beds made of bricks or concrete and holding 6 to 9 in. of soil. The beds are built immediately above ground level. When the soil has to be sterilized, several methods are possible: Hoddesdon, Comb, Drain Tile as described above for benches, and by Inverted Trays.

All of these methods have their advantages and disadvantages. With Hoddesdon pipes the disadvantage is that all the soil must be moved, also the pipes. The soil is not moved in the other three methods. With Combs, special spikes are necessary, 4 to 6 in. long according to the depth of the bed. The Drain Tile bench method should work with raised beds made of concrete but special precautions would be necessary if the edges were broken, thus preventing a good steam seal. The Tray method necessitates the making of metal trays 5 to 10 ft. long and just wide enough to fit between the walls of the beds and 4 to 6 in. deep. Such trays, which must be suitably reinforced, are fairly heavy but they could be lifted and moved with ease by two men, one each side of the bed. On the whole, it seems that the Comb method would be the best way of sterilizing soil in raised beds.

SUMMARY

1. 'Balanced steaming' is put forward as the fundamental requirement for the improvement of the steam sterilization of glasshouse soils. In balanced steaming the output of steam from the Hoddesdon pipes is matched (balanced) with full steam output from the boiler, i.e. if the boiler output is 1,500 lb. steam/hr., then the Hoddesdon pipes must deliver 1,500 lb. steam/hr. to the soil.
2. Balanced steaming is automatically ensured by using the correct total length of Hoddesdon pipe for a given boiler size.
3. A consequence of balanced steaming is that the steam pressure at the Hoddesdon pipe is no more than 2 psi. As an alternative to consulting Table 10, balanced steaming can be ensured by increasing or decreasing the total length of Hoddesdon pipe until a pressure gauge fixed to one of the pipes shows 2 psi. Thus, beyond a pressure gauge to make certain the header pressure is 2 psi, no special apparatus is required. Balanced steaming is efficient and economic.
4. Neither normal fluctuation in boiler pressure nor variation in steam main length will materially affect header pressure. Consequently, a reducing valve is never necessary with low-pressure boilers and only in special circumstances with high-pressure boilers.
5. Balanced steaming does not increase the labour or the time required for treating a given area of soil.
6. Full details are given for steaming by the Hoddesdon method; long pipes are to be preferred to short. Steaming is continued until the surface layer of soil is 212° F. The steam is then turned off and the sterilized soil is left covered for a further 20 minutes or so. This does away with the need for 'trickle' steaming except when there is heavy disease infection.
7. Mention is made of the Grid, Harrow and Tray methods of steaming but they can no longer be recommended as having any special merits.
8. Full details are given of a modification of the Spike Harrow

method, namely, the Comb method. The unit is a 'Comb' of spikes spaced on a long, single pipe. A number of Combs are used together, according to boiler capacity.

9. An account is given of the Drain Tile method as practised in U.S.A. for glasshouse borders and benches. The tile are permanently buried. Capital costs are high but running costs very low.

CHAPTER 14

STERILIZING IN GLASSHOUSES: FUTURE METHODS

IN the last chapter we saw how the better of the current methods could be 'modernized' on the basis of the recent findings of research. In one sense the modern methods recommended in Chapter 13 still belong to the future, i.e. the very great majority of growers have yet to adopt them in place of their old, inefficient practices.

In this chapter mention will be made of two methods, neither of which has yet been put into practice in Britain. Both must be regarded as in the early testing-out stage, both promise well. Either of them can lead to new and large economies in steam sterilization.

One of these, the 'Steaming Plough' method, eliminates nearly all the labour of digging, the coupling and uncoupling of pipes and the moving of equipment from plot to plot. This saving of labour is of such great importance as to demand the concentrated interest of both the research worker and grower in the clearing-up of remaining difficulties, if any. The other innovation, the steam-air ejector, involves the admixture of air with steam such that the temperature of the steam is, say, 180° F. instead of the usual 212° F., thus saving fuel. The salient features of these new methods are given below.

Steaming Plough

Recently, a steaming plough hauled by a wire and electric winch has been developed in Denmark. It consists of a header and six (or other number) 6½ ft. long pipes joined to a framework at the front of the plough (Fig. 31). The front end of each pipe is pointed, the next 2 ft. comprises a shaped junction with the header and the remaining 4½ ft. is drilled with two rows of 2·5 mm. holes, similar to the arrangement in a Hoddesdon pipe. A plastic sheet fixed to the framework of the plough is carried along by it and covers the area of soil that is being steamed (the sheet should also cover the plot previously steamed). The plough is coupled by means of a steel hawser to an electric winch (Fig. 32) at the far end of the house. The winch is anchored in one corner of a gable end and from there the hawser is led through a loose pulley hooked into the wall on a level with and opposite to the track of the plough. The speed of winding can be finely adjusted.

One man operates the oil-fired boiler, adjusts the winding rate of the winch, returns the plough for its next run and couples the steam pipe. The price in Denmark of winch and plough complete is about £100. It is essential that the soil is rotary cultivated thoroughly to a depth of about 1 ft. before using the plough.

A possible improvement to the plough would be to weld a shaped blade in the form of a half spear-head to the underside of the pointed end of each pipe to act as a subsoiler. By loosening the soil beneath the pipes sterilizing in depth might become possible.

It is claimed that the plough, when set in position, does not ride up or dig down into the soil. It readily operates at a soil depth of 10 to 12 in. and the speed is 6 to 12 metres/hr., 'dependent on the quantity of steam available.' It has also been used deeper.

Steam-Air Ejector

This piece of apparatus permits the controlled mixing of air with steam, based on the principle of the Venturi tube. In other words, the steam is 'diluted,' therefore goes further, with a corresponding saving of fuel. Experiments at the John Innes Horticultural Institution (10) under practical conditions have shown that the sterilizing of glasshouse soil by means of the steam-air ejector is as easy and thorough as with conventional apparatus. Even when the best practice was followed (i.e. balanced steaming, dry soil, etc.) an additional fuel saving of 15 per cent was achieved when the temperature of the steam-air mixture was 180° F.

PEAK STERILIZING

Progress in horticultural husbandry springs from the putting together, in correct sequence, of methods each known from scientific investigations to be the best of its kind. I have called this the 'principle of integration' (20). It can also be styled 'the synthesis of success.' By it we can reach the very peak of efficiency and profitability.

Fundamental to both these notions is the deliberate exclusion or dropping of mediocre or even good methods and replacing them by the best. This can only be done when all, or nearly all, the facts are known. Have we reached this position with respect to the steam sterilization of glasshouse soils? The answer is, I think, 'yes.' We have all the basic technical information. We have wide experience of the requirements of crop production under glass. We have enough information to justify our looking ahead and defining with some rigour the ideal but fully practical method of sterilizing glasshouse soils.

You will notice I have used the word 'method' in the singular as if there were no alternatives. I mistrust alternatives in glasshouse management. True, the art of compromise* might almost be described as the essence of the art of growing. But compromise need not, and should not, mean the lazy continuance or adoption of second-best methods. When the facts are known then, within quite wide limits only one method, or combination of methods, is acceptable. Any modifications or alternatives will be second-best. Unfortunately, human nature being what it is, most of us accept the second-best for reasons so flimsy that they would never stand the scrutiny of, say, the shrewd investor or wise business executive.

What, then, on the small- to medium-sized nursery, is likely to be the ideal method of steaming glasshouse soil in the near future? The attaining of this method should be the objective of all glasshouse nurserymen, for it will combine the highest efficiency with high economy. Table 12, on the following page, constitutes my answer.

By using a high-pressure boiler, a steam-air ejector could be mounted on the plough after the drier and sterilizing done at 180° F. With a low-pressure boiler, the air would have to be supplied by a low-pressure high-volume compressor and mixed with the steam after it had passed through the drier.

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* The adjustment of conflicting courses of action by modification of both.

If the above views are right then steam sterilization, correctly integrated into nursery practice, may well become the most economical as well as the most efficient method of ridding soil of pests and diseases and in restoring fertility.

Table 12

Best method	Advantages
Soil	
dry, rotary cultivated, fine tilth, loose	minimum heat requirement, maximum rate of steam penetration
Boiler	
low pressure (10 to 25 psi) 80 per cent thermal efficiency, oil fired	maximum combustion efficiency, steady fire, uniform steam pressure
Steam Mains	
(i) light alloy irrigation pipes, 2½ to 3 in. dia., quick couplings	dual purpose, easy and quick to handle, low heat loss, therefore reduces labour and fuel costs
(ii) flexible rubber hose	permits use of steaming plough
Auxiliary Apparatus	
(mounted on steaming plough)	
(i) steam-pressure gauge 0 to 10 psi	ensures check on balanced steaming
(ii) steam drier and trap	gets rid of condensed steam
(iii) cylinder (pipe) header	ensures uniform steam distribution to any number of pipes
(iv) plastic sheet	ensures sterilization of surface of soil
Steaming Plough Unit	
(i) plough, electric winch and cable	reduces labour to minimum
(ii) correct number and length of Hoddesdon pipes, arranged according to shape of house	ensures balanced steaming with maximum economy of fuel and labour

Whatever may be said about my views on the peak method of soil sterilization, this much is certain. There appears to be no prospect of further advance in the steam sterilizing of glasshouse soils once the modern methods described in this book (Chap. 13) have been adopted. Labour costs can only be reduced by mechanization.* Fuel costs can only be reduced by using less steam. So either the steaming plough–steam-air ejector combination will enable another advance to be made, or we have already reached finality in the steaming of glasshouse soils.

SUMMARY

1. The labour incurred in the sterilizing of glasshouse soils is one of the two largest costs. Most of the labour is eliminated by using a steaming plough.
2. The second largest cost is fuel. This can be still further reduced by the use of a steam-air ejector.
3. The conception of peak sterilizing is put forward as the objective for the near future. It consists in combining the best individual apparatus and methods to give the highest efficiency and economy.

* On large tomato, rose and similar specialist nurseries, where facilities may be exceptional, the Drain Tile method might be a better proposition than the Steaming Plough method.

CHAPTER 15

STERILIZING BY ELECTRICITY

JUST as solid fuel, oil, and gas can be used to produce heat for soil sterilization, so can electricity. Three methods are available, (1) indirect heating, (2) direct heating, and (3) steam heating. All apply to sterilization in bins or on benches.

Indirect Heating (Immersion Sterilizers)

Description. Electricity is used to produce heat indirectly by passing it through a thin wire which, because of the resistance it offers to the current, becomes very hot. This is the principle used in electric fires. If the wire is wound on a refractory former and enclosed in a metal tube from which it is suitably and safely insulated, the tube is heated by the wire and can then be used as a *heater*. This is what is done in the case of the familiar tubular immersion heater employed for heating water. The water in contact with the heater becomes hot, moves away and is replaced by colder water. Thus, the whole mass of water is circulated over the heater by *convection* and heats up to a highly uniform temperature.

An immersion heater can also be used to heat soil with one important difference. Soil cannot flow like a liquid, therefore it is heated by vapour movement and by *conduction*, not by convection, i.e. the heat from the tube has to travel from one particle of soil to another until the whole mass is heated. Since the conduction of heat from particle to particle is rather slow* the soil nearest the heater is at a high temperature for a longer time than soil some inches away. Heating is *not* uniform (21). This would be of little consequence if the temperature of the heater were not more than 212° F. (cf. steam heating). But unless the surface of the heater is at a temperature of 500 to 600° F. the rate of heating the soil is, in general, too slow to be economic. Thus, when electricity is used to heat soil indirectly, the heaters should, as far as possible, (1) have a large heating surface, and (2) be closely spaced (e.g. not more than 6 to 8 in.). By observing these requirements satisfactory soil sterilizers, employing the indirect heating principle, have been designed and are available as proprietary models in which the heaters are of tubular or plate construction.

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* e.g. it may take 1 hour for the soil to reach 212° F. at a distance of ½ to 1 in. from the heater (20).

Immersion sterilizers will heat the soil to 180° F. with an expenditure of electrical energy from 1·0 to 1·75 kilowatt-hours per cubic foot of soil, depending on (1) the electric loading of the sterilizer, and (2) the kind of soil, its initial temperature and its moisture content. The load is constant throughout operation. In Britain, the tendency is to use a fairly heavy loading (e.g. 1,300 watts per cu. ft. soil heated to about 180° F. (76° C.)) in order to keep the sterilizing time down to about 1½ hours and thus permit four or five lots of soil to be sterilized in one day. In U.S.A. (1) a lighter loading (e.g. 300 watts per cu. ft. soil heated to about 170° F. (70° C.)), is commonly employed, with a consequent increase in the sterilizing time to 4 to 5 hours for each lot of soil.

It will be noted from the figures given above that the soil in immediate contact with the heaters is much overheated. Now, we have seen (page 22) that it is undesirable that soil should be heated above 212° F. for more than a short time, hence the question arises, is this baking of the soil around the heaters subsequently detrimental to seedling growth? The answer from experiment is 'no,' presumably because the amount of overheated soil in an immersion sterilizer is only a small percentage of the total volume of soil, e.g. less than 8 per cent in one model.

The moisture content of the soil is an important factor in shortening the time of sterilizing and in saving electricity. Thus, in one experiment with an immersion sterilizer, increasing the moisture content from 19 to 25 per cent put up the current consumption by 64 per cent (cf. page 42). Efficient thermal insulation of the sterilizer materially assists in reducing heat loss and, therefore, current consumption also.

Examples, with respect to soil capacity, sterilizing time, electric load and cost of sterilizer, of proprietary immersion-type sterilizers available in Britain, are:

1. 5¼ bushels (¼ cu. yd.), 1½ hours, 9 kW, about £70.
2. 1 bushel (1·3 cu. ft.), 1½ hours, 1·5 kW, about £20.

Method of Using. Most immersion-type sterilizers consist of a 'box' on legs, such that the soil is loaded into it from above and discharged on to the floor by opening the bottom of the box. The heaters may be arranged horizontally or vertically.

There are only two points to watch in using immersion-type sterilizers. First, the soil should be no moister than will barely permit it to retain its shape when squeezed firmly in the hand. Second, the soil should not be packed or rammed into the sterilizer, otherwise there will be difficulty in emptying it. All that is required is just enough pressure to settle the soil around the heaters.

Direct Heating (*Electrode Sterilizers*)

Description. An alternative to the indirect application of heat to soil by means of electric immersion heaters, is to pass electricity directly through the soil from one metal plate, or electrode, to another. More correctly, the current flows through the water (moisture) on the surface of the soil particles. No current will flow through perfectly dry soil.

Now, water offers considerable resistance to the passage of electricity, consequently it becomes hot in just the same way as does a thin wire. This heat is transferred to the soil particles by moisture movement. Actually soil water is not pure water but contains dissolved salts, i.e. it is a weak electrolytic solution. It is characteristic of such a solution that its electrical conductivity increases with increase in temperature. In other words, as the temperature rises, the current rises too. This is precisely what happens in electrode sterilizers. Indeed, if the resistance of a particular soil is so high that an adequate current will not flow, the soil can be watered with an artificial electrolytic solution made by dissolving an appropriate chemical salt, e.g. magnesium sulphate, in tap or rain water.

When an electrode steriliser is first switched on the soil offers the maximum resistance. As heating proceeds the resistance falls until, towards the end of sterilizing, the current flowing is three to four times the initial value. Finally, when the soil temperature has reached a high value, e.g. 200 to 210° F., the current is automatically reduced to a low value (it is 'cut off'), due to the formation of a thin layer of steam next to the electrodes and/or to the drying-out and consequent shrinkage of the adjacent soil. The point at which this cut-off occurs depends on the initial moisture content of the soil. With the loams ordinarily used for seed and potting composts a temperature of over 180° F. is almost certain to be reached. The more rapid the heating the lower the heat loss from the outside surfaces of the sterilizer.

In general, a soil moisture content of about 30 per cent is the optimum for rapid heating and the maximum current likely to flow should be determined at this moisture content so as to ensure that the connected supply is adequate. The electrical resistance of the soil is directly proportional to the distance apart of the electrodes and inversely proportional to their area, i.e. doubling the distance doubles the resistance, doubling the electrode area halves the resistance. Many spacings of electrodes have been investigated with respect to the several other factors to be considered. A spacing of about 10 in. may be reckoned typical in practice on a 230 to 240 volt supply.

In Britain, the electrodes are employed in a vertical position, and are part of the soil container which is removed for emptying. In U.S.A. horizontal electrodes seem to be preferred in a box, the bottom of which opens to discharge the soil. The author has compared vertical with horizontal electrodes and with the latter found it more difficult to obtain adequate pressure between the upper horizontal electrode and the soil and thus ensure good electrical contact. Also, the heating of the soil was somewhat less uniform.

An advantage of electrode sterilizers is that thermostatic control can be used to cut off the current when the temperature reaches 180° F., thus economizing in time and electricity. In general, the electrode sterilizers take ½ to 1½ hours to heat soil to 180° F. or more and consume 1·0 to 1·5 kilowatt-hours of electricity per cubic foot of soil.

Since an electrode sterilizer is usually connected directly to the mains and the soil is, therefore, 'alive,' it is extremely important that the sterilizer should be electrically interlocked to prevent access to the soil while the current is on.

Examples, with respect to soil capacity, electric load and cost of sterilizer, of proprietary electrode sterilizers available in Britain are given below. The sterilizing time per charge of soil for these particular models is given as 30 to 45 minutes.

	Approx. soil capacity (bushels)	*Phase*	*A.C. voltage*	*Max. current per phase (amps.)*	*Approx. price*
1.	⅓	Single	230/250	6–8	£10
2.	1¼	Single	230/250	20–28	£25
3.	6¼	Three	400/415	25–40	£110
4.	12½	Three	400/415	35–45	£170

Method of Using. Two factors must be borne in mind when using electrode sterilizers. The first is the variable characteristics of soils, some having a high resistivity, e.g. sandy soils, others a low resistivity, e.g. organic or muck soils, with intermediate classes. Secondly, resistivity also depends on the moisture content of the soil and on its compaction in the sterilizer (22). Hence, the size of the current that flows through the soil will vary from soil to soil and according to how the soil is handled. It is an advantage, therefore, that an electrode sterilizer should be fitted with an ammeter to indicate what current is flowing. Should the initial amperage be too low, then the soil must be made moister and firmer. In difficult cases an electrolytic solution (23) can be used to wet the soil, e.g. 1 oz. of magnesium sulphate or superphosphate dissolved in one gallon of water. Should the initial current be too high, the soil must be used drier and looser in the sterilizer. Since, in practice, it is customary to keep a stock of loam from which smaller lots are drawn for sterilizing and compost making through the year, then the requirements for operating the sterilizer to the best advantage have to be found once only. Thereafter, sterilization is mere routine.

A comparison of immersion and electrode sterilizers will be found in Table 13. Provided electricity is available at a low rate, it offers a clean, cheap and efficient method of sterilization with both types of sterilizer.

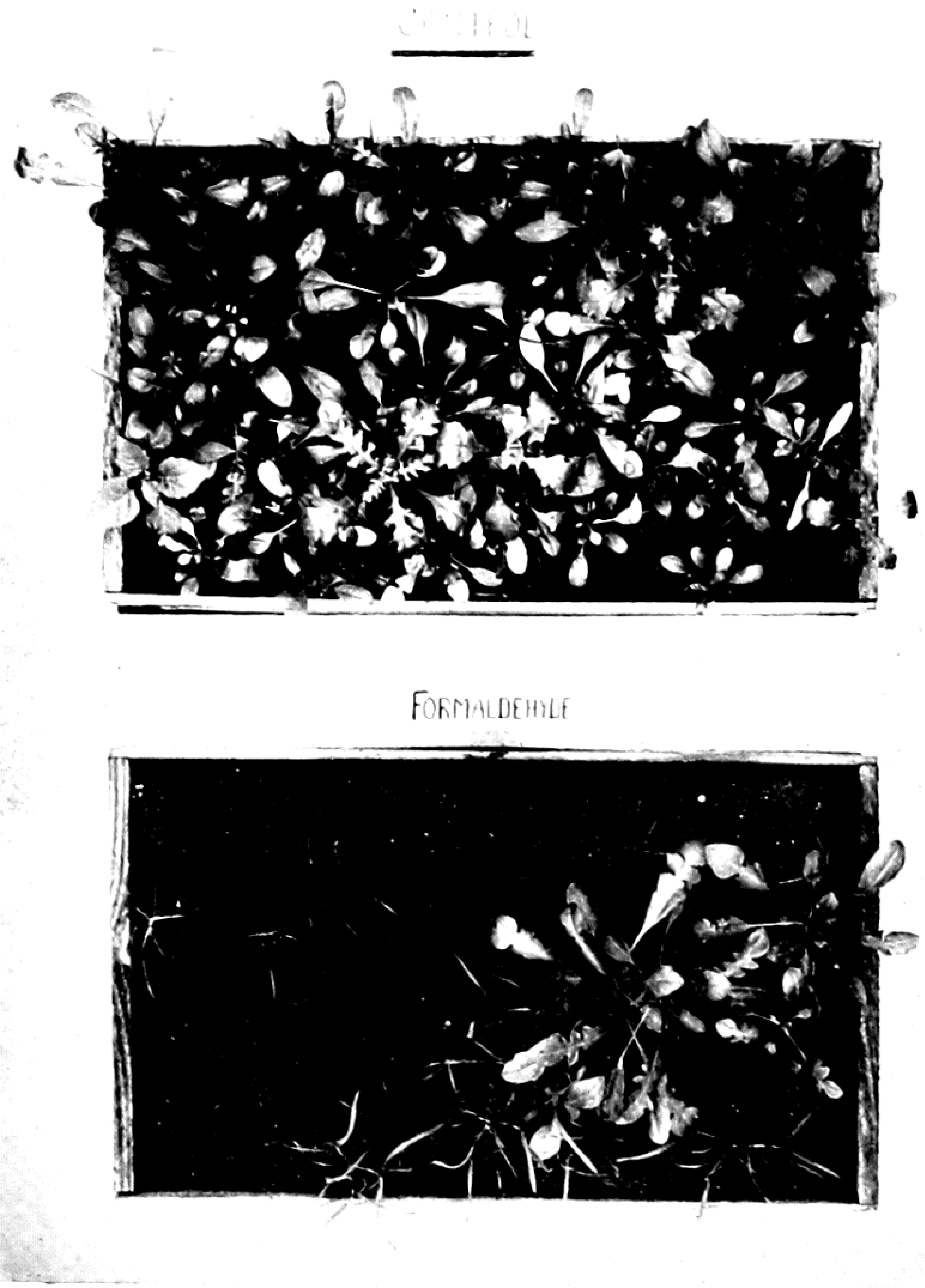

FIG. 33.—Showing the selective action of a chemical sterilizer against weeds.

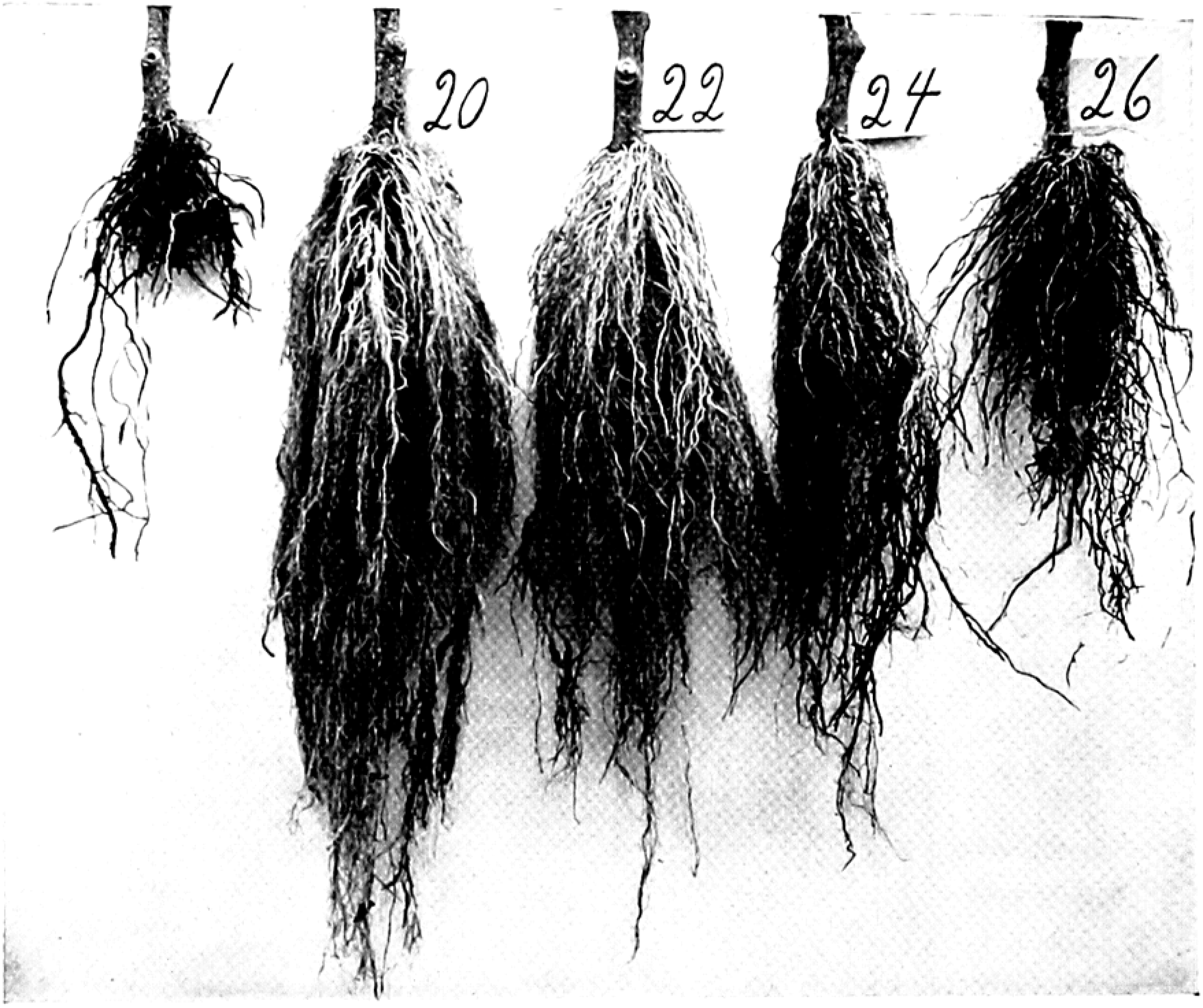

Fig. 34.—The effect on tomato roots of adding infected soil to steamed soil. 1, growth in unsteamed infected soil. 20, growth in steamed soil. 22, 24 and 26, growth in the same soil as 20, but after addition had been made of 0·1, 1·0 and 10·0 per cent, respectively, of the soil used for 1. This illustration is a warning against re-infection of sterilized soil through careless and unhygienic methods.

Table 13

COMPARISON OF IMMERSION AND ELECTRODE STERILIZERS

Item	Immersion sterilizer	Electrode sterilizer
Electrical loading	constant at all times and with all soils	variable at any one time and between soils
Effect of increase in soil moisture content* on:		
(i) current	none	increases initial and maximum current
(ii) operation of sterilizer	increases time	decreases time and raises cut-off temperature
Effect of increase in soil compaction* on:		
(i) current	none	increases initial and maximum current
(ii) operation of sterilizer	very little	decreases time and raises cut-off temperature
Heating of soil	not uniform	highly uniform
Overheating of soil	possible	impossible

* Within normal working limits.

Steam Heating (Electrical)

Where it is not possible to burn solid fuel for steam generation electric heaters may, ocasionally, be an economical substitute. Experiments in U.S.A. have revealed two ways of using electricity for the steam heating of soil.

In the first method (1) a tight, insulated cabinet 29 in. high, 28 in. wide and 15 in. deep was fitted with trays ('flats') 3 in. deep to hold the soil. Steam is generated at atmospheric pressure in the base of the cabinet by a 1,500 watt electric hot plate forming the bottom of a metal pan holding 5 quarts of water which can be brought to the boil in 30 minutes. The current is left on for nearly 2½ hours during which 3 quarts of water are evaporated and the soil temperature rises to 60 to 70° C. (140 to 158° F.). The average current consumption per cubic foot of soil was 1 to 2 kilowatt-hours, depending on the nature of the soil.

Other Methods

Continuous Electric Sterilization. An ingenious attempt to mechanize soil sterilization on the lines of the modern electric bakery also hales from U.S.A. (1). A continuous chain operated by a ⅓ h.p. electric motor drags soil from a hopper in small heaps ½ in. deep, across a horizontal stainless steel table 6 in. wide and 64 in long. The table is heated from below by a number of electric strap heaters and from above by six 1,000 watt bowl heaters, the total consumption being 10 kilowatts. The mechanism is fully enclosed and thermally insulated. After the initial heating up period, about 6½ cu. ft. soil can be treated at a temperature of 65 to 80° C. (149 to 176° F.) in one hour using approximately 1·5 kilowatt-hours of electricity.

Sterilization of Glasshouse Soils. From time to time enquiries and investigations have been made in various countries to ascertain whether electricity can be satisfactorily employed for the sterilization in situ of glasshouse soils. Direct heating grids made of ¼ in. diameter electrodes spaced 3 in. apart and electrode immersion-type boilers for raising steam, have all been considered. All methods require 2 or more hours for the treatment of an area of soil no larger, and usually smaller, than when conventional steaming is practised. And in all cases the connected load (70 to 90 kilowatts) for an adequate soil area would be larger than any nursery could accommodate. Thus, we must conclude that it costs too much to install electrical apparatus for in situ sterilizing. In any event, having regard to the time factor in the general economy of the British nursery, electrical sterilization of glasshouse soil takes too long to be acceptable.

SUMMARY

1. Where steam cannot be used for bin sterilizing, electricity can be employed directly or indirectly. Both methods have given satisfactory results.
2. In the indirect or immersion method of sterilizing, the soil is heated by immersion heaters. Electrical loading is constant, but heating is not entirely uniform and partial overheating is inevitable.
3. In the direct or electrode method the current flows through the soil. Electric loading varies considerably, but heating is highly uniform and overheating impossible.
4. Electrical sterilizing of glasshouse soils in situ is not practicable. It takes too long and costs too much.

PART II

CHEMICAL STERILIZATION

When it is impossible or uneconomic to sterilize soil by steam to do so by a chemical may be a useful alternative (24).

Chemical sterilization, however, is not so thorough as steaming. Steam, properly applied, eliminates equally all pests, diseases and weed seeds. But chemicals are selective in action (Fig. 33). A given substance (e.g. cresylic acid) may be more effective against pests than diseases or vice versa (e.g. formaldehyde). Indeed, a given chemical may be more lethal against one particular pest (or disease) than another. Thus, before using chemicals it is important to know whether pests or diseases are the major trouble and sometimes which particular pest or disease has to be dealt with.

Before discussing the action and use of the various chemical sterilizers, we must briefly consider their effect on soil life, soil chemicals and soil structure. In general, chemical sterilizers have an effect on soil micro-organisms and soil chemicals equivalent to that obtained by heating soil to 140 to 170° F. (60 to 75° C.), e.g. in both cases the soluble organic matter is increased to about the same extent. The position with regard to soil structure is somewhat different. Steam improves the structure. Chemicals, as used, either have no effect, as when gases are employed (e.g. chloropicrin), or may cause some loss of structure as when large amounts of water are the vehicle for the chemical (e.g. formaldehyde). As a rule, this is of no consequence so long as the soil is not trampled on while it is wet. In general, it may be assumed that chemical sterilizers penetrate soil to a depth of not more than 10 in. in one application.

Chemical sterilizers may be conveniently divided into gases, liquids and solids. The more important types and the methods of using are described in the chapters which follow.

CHAPTER 16

BY CHLOROPICRIN

Description. Chloropicrin is a heavy, practically colourless to pale yellow liquid which readily volatilizes into a pungent 'tear gas.' Its chemical name is Trichloronitromethane (CCl_3NO_2). Chloropicrin is almost insoluble in water but is soluble in alcohol, petrol (gasoline) and other organic solvents. It weighs 1·65 times as much as water. The pure material is completely volatile and leaves no residue in the soil after aeration. Since chloropicrin is non-inflammable there is no danger of explosion or fire in using it either in the liquid or gaseous state. The vapour has a sweetish, pungent odour which quickly produces tears, also nausea even if low concentrations are breathed, but no permanent injury or effects result. In any case, little inconvenience is caused to the operator who uses an injector to apply chloropicrin. Chloropicrin has a corrosive action on metals and rubber. For this reason, all rinsing of apparatus should be done with paraffin (kerosene) or petrol (gasoline) followed by light oil. Water should never be used.

Action. Chloropicrin is a good fungicide and insecticide and is also highly effective against weeds and weed seeds. It appears to give better control of root-knot eelworm (*Heterodera marioni*) than potato eelworm (*Heterodera rostochiensis*), but it is not so effective against eelworms as ethylene dibromide or DD.

Chloropicrin is widely used on a variety of soils and under a variety of conditions in U.S.A. and New Zealand but has been tried in Britain only in a small way. Its introduction, therefore, seems overdue, especially as there appears to be no reason why it should not be equally successful here as overseas. It is the best and only general-purpose chemical sterilizer and ranks next to steam in all-round efficiency.

Costs. The cost of chloropicrin in Britain at 34 gall./acre *roughly*, to a full spit and let it dry out for a day or two. Then winter flood if necessary and, when soil is dry enough, fork over once more. Do not plant until 6 weeks after application of chloropicrin.

Injectors. In North America and Australasia, where chloropicrin has been used, special containers and injection apparatus are available. In Britain, DD (page 142) injector-guns have proved serviceable.

Safety Precautions. (1) *Persons.* The fact that chloropicrin is a tear gas renders it safe to the operator since no one can willingly remain in a glasshouse or room that contains more than a very small amount of the lethal concentration. The opening of cylinders and filling of injectors should be done out-of-doors wearing a respirator and eye-shield to give protection against accidental splashing. A civilian-type respirator (gas mask) should be used in glasshouses and rubber gloves, boots and an apron should be worn. *Keep chloropicrin off the skin.* If some accidentally comes in contact with it it should be wiped off *at once* and soap and water used freely to rinse the skin. If the liquid is spilled on clothes, the affected garment, shoes, etc., should be *promptly* removed.

(2) *Plants. Chloropicrin is highly toxic to all plant life.* Out-of-doors, cylinders, etc., should not be opened within 10 yd. of the ends of the glasshouses and never *between* them. Indoors, every care should be exercised to avoid the spilling of even very small quantities of chloropicrin. Doors and openings between glasshouses or sections should be carefully sealed to prevent even low concentrations of the gas from coming into contact with plants.

SUMMARY

Chloropicrin is the only general-purpose chemical sterilizer approaching the effectiveness of steam. It is widely used in various parts of the world but has never been adequately tried in Britain. Chloropicrin is injected into glasshouse soils at 12 in. centres and about 6 in. deep. The cost per acre is about £200, including application.

CHAPTER 17

BY FORMALDEHYDE AND TAR-ACIDS

Description. 'Formaldehyde' sold for horticultural use is a solution containing 37·5 to 40·5 per cent formaldehyde gas and is usually referred to as 40 per cent commercial formaldehyde. A stabilizer (< 10 per cent methyl alcohol methanol) is included to deter 'polymerization,' i.e. the changing of the liquid to a solid (paraformaldehyde). Formaldehyde quickly deteriorates at low winter temperatures, therefore in cold weather drums and tins should always be kept under cover. It should be used as fresh as possible.

Action. Formaldehyde is, perhaps, the best alternative to steaming where control of fungal diseases and maintenance of fertility are concerned. It is not effective against such insect pests as eelworms, symphilids and woodlice, neither does it control *Verticillium* wilt satisfactorily. Formaldehyde controls the germination of weeds in varying degree. Thus, in one of the author's experiments, there was 100 per cent control of shepherd's purse (*Capsella bursa-pastoris*) but only 30 per cent of chickweed (*Stellaria media*).

Costs. Using a 2 per cent solution applied at 5 gall./sq. yd., the cost per acre for the material is about £110.

Method of Using. For soil sterilization commercial formaldehyde is diluted with water. Success depends on penetration of the dilute solution to every particle of soil at the requisite depth, its retention in the soil for an adequate length of time and thorough clearance of the fumes before potting or planting begin. Because soil does not absorb formaldehyde appreciably (cf. cresylic acid) it will penetrate only as far as the water that carries it. Thus, a large amount of water must be used to carry the formaldehyde well down into the subsoil. Roughly speaking, a heavy soil requires twice as much water as a light one, to wet it to a given depth.

Penetration is ensured by seeing that the soil is loose, friable and moist (potting condition). Formaldehyde should not be used when the soil temperature is 40° F. or less.

Retention is almost inevitable since the fumes are given off slowly (especially in winter) and consequently act over a long time. In some cases, covering the soil may be beneficial (page 134).

Clearance can be accelerated by (1) putting on a little heat in the glasshouses, (2) digging over the soil about 3 weeks after the formaldehyde is applied, or, in the case of potting soil, spreading it out to air. *No seed sowing or planting should be attempted until every trace of smell has gone.* Normally this takes at least 6 weeks. When flooding of a glasshouse soil is necessary, it is an advantage to do it after the formaldehyde has been used, towards the end of the 6-week period.

Dosage and Application. Formaldehyde is generally diluted to a 2 per cent solution, or 1 part of commercial formaldehyde to 50 of water. The amount of this solution to be applied to the soil depends on the particular treatment.

1. *Soil in Heaps*

(*a*) *Small heap.* To 1 bushel of soil add 1¼ gall. of dilute solution (¼ pint formaldehyde to 1¼ gall. water) and thoroughly mix with spade. Cover the heap with sacking for 48 hours. Uncover the heap and spread out the soil to dry. Turn the soil several times during the next few weeks to assist fumes to escape. Do not plant until at least 4 weeks have elapsed. Placing the soil in a warm, empty house or over heating pipes shortens this period.

(*b*) *Large heap.* Spread out a layer of soil 6 in. deep. *Soak* this layer with dilute solution at the rate of 3 to 5 gall./sq. yd.* (more if necessary). Add another layer of soil and repeat the process until all the soil has been treated. Cover the heap for 48 hours, then uncover it and turn the soil several times to hasten the clearance of the fumes.

2. *Glasshouse soil*

(*a*) *Surface application after digging.* Water thoroughly a dry soil a week or so before sterilizing so that it is in potting condition at the time of treatment. Water lightly a dry soil surface a few days before sterilizing. Work the soil, including the pathways, into a fine, loose condition, breaking up all lumps. Leave the soil surface as level as possible to avoid puddles forming when the formaldehyde is applied. Measure in square yards the area to be treated, e.g. in strips 1 yd. wide across the house. Make up the dilute solution in a tank or barrel of suitable size and known capacity and raise it on a bench, trestles, lorry, etc. Alternatively, use a tank at ground level and a pump of known delivery. Attach a coarse sprinkler or rose to the nozzle of the hose-pipe and, 1 ft. back from the nozzle, insert a water meter, one dial of which measures 1 to 10 gall. Alternatively, measure the rate of the flow of water from the hosepipe (number of gallons per minute) and apply the solution on a time basis using, if necessary, a cock on the nozzle to control rate of flow. Avoid kinking the hosepipe. The time-basis method is unreliable if the static head (pressure) of the water varies much (it usually does in water mains). Apply 2 per cent formaldehyde solution at the rate of 3 to 5 gall./sq. yd. according to the severity of disease infection. Avoid flooding, hence uneven, inefficient application, by applying the solution no faster than the soil can absorb it. Pay special attention to brick walls, concrete dollies, etc. Expose them and thoroughly water them with the solution. Keep the glasshouse closed for 2 days and then, if possible, turn on a little heat and ventilate the house.

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* Equivalent to 20 to 30 gall./cu. yd.

(*b*) *Application during digging.* Dig the soil one spit deep, applying the formaldehyde solution to the surface of the soil as *each* trench is completed. When deep sterilization is necessary double dig the soil and apply the solution to both top and second spits, at the rate of 2½ to 5 gall./sq. yd./spit.

(*c*) *Application to trenches.* For deep sterilization when disease has been severe, double dig the soil and apply the solution to the surface of both top and second spits.

Safety Precautions. (1) *Persons.* Rubber gloves and boots should be worn, also an eye-shield when the concentrated formaldehyde is being handled. Glasshouses should be well ventilated while formaldehyde is being applied.

(2) *Plants. Formaldehyde fumes are highly poisonous to plants.* When a glasshouse containing plants adjoins the house being

treated care should be taken to see that connecting doorways, ducts, broken panes, etc., are sealed off. If, when it is desired to begin planting, there is any doubt as to whether all fumes have cleared, one or two young plants (e.g. tomato) should be planted here and there in the soil and the ventilators closed. Damage to the leaves will be evident within 24 hours if fumes remain in toxic amount.

TAR-ACIDS

1. *Cresylic Acid*

Description. Cresylic acid or liquid carbolic acid, of 97 to 99 per cent purity, is derived by distillation from crude tar acids and consists mainly of phenol and the three isomeric cresols. It is only moderately soluble in water but is readily absorbed on soil particles. Consequently, if, as has been the practice, cresylic acid is 'diluted' with water, the latter passes through the soil leaving the cresylic acid behind in the surface layers. It follows that (1) the penetration of cresylic acid is less than that of formaldehyde, and (2) if cresylic acid is to be of any value at all the soil must be turned over, one spit deep, after the material has been applied.

Cresylic acid has largely gone out of use in recent years, partly for the reason that steaming, now so widely practised, controls most pests of consequence. Hence, in those years when the soil is not steamed, the small amount of disease that arises from reinfection of steamed soil is best dealt with by using the fungicide, formaldehyde.

Action. Cresylic acid is less efficient than formaldehyde in killing fungi and does not satisfactorily control eelworms. It is of value for the suppression of millipedes and woodlice.

Method of using. In the past, cresylic acid has been used as a mixture of 1 gall. in 40 gall. of water and applied at the rate of about 4 gall./sq. yd. using a hose, spray lance or hollow-tined fork. It takes 4 to 6 weeks, according to soil type and temperature, for all traces of smell to disappear.

2. *Proprietary Tar-acid Fluids*

Improved forms of the cresylic acid type of sterilizer are available which, though they may contain compounds less soluble than cresylic acid, are made into emulsions which remain stable. They can thus be evenly distributed throughout the soil with uniform results.

Costs. The cost, per acre, for the material ranges from £40 to £140, according to the brand of sterilizer.

SUMMARY

1. Formaldehyde is the most widely used chemical sterilizer in Britain, almost entirely because of its good fungicidal properties. For glasshouse soils it is applied as a dilute solution. Its successful use depends largely on penetration of the liquid in adequate amount deep into the soil, i.e. the soil must be loose, friable and moist. The cost of the material is about £110/acre.

2. Cresylic acid has been fairly widely used in the past. Its continued use no longer seems justified. Improved proprietary tar-acids are available. The cost of these ranges from £40 to £140/acre.

CHAPTER 18

NEMATOCIDES

CHLOROPICRIN, formaldehyde and, to a lesser extent, tar-acids, are chemicals which, though differing qualitatively in their efficiency, are used chiefly for their general sterilizing effect.

There is another group of chemicals which, while not soil sterilizers proper, are sometimes used in conjunction with, or alternative to, steam and other chemicals for the control of a specific pest, namely eelworms (nematodes). These soil fumigants are also effective against various insects, but by far their greatest usefulness is in controlling nematodes. We may, therefore, call them nematocides (25). A short account of the most important of these chemicals is given below.

DD Mixture

DD is a proprietary product consisting mainly of a mixture of dichloropropane and dichloropropylene. It is a slightly oily, completely volatile, highly inflammable brownish liquid, with a pungent, somewhat nauseating odour. It is about one-fifth heavier than water.

DD is now in fairly wide use for glasshouse crops and, on the whole, has given highly satisfactory results. It is very effective in suppressing root-knot eelworm in tomato and cucumber houses. Its precise action against potato eelworm is not yet clear. DD gives better control of root-knot eelworm than steaming, probably because the vapour penetrates deeper than the heat from the steam. DD is also effective against wireworms and insects. It has rather limited fungicidal properties. The cost per acre is about £40 for the material and £5 for labour. An injector gun costs £4 10s. 0d.

DD is applied, preferably in the autumn, by means of an accurate hand injector at 12 in. to 15 in spacings, the usual dosage being 3·6 and 5·7 ml. respectively, equivalent to 300 to

400 lb/acre.* A 15 in. spacing is satisfactory for most glasshouse soils but closer spacing gives a more uniform distribution of the chemical. The soil surface should be sealed promptly with water (page 134); light and crumbly soils may be rolled. All paths should be treated and special attention given to soil adjacent to hot-water or steam pipes, where eelworms thrive. It is of little use eliminating eelworm in the bulk of the soil if corners, paths and similar awkward or small areas are left from which the pest can rapidly re-infest the rest of the house.

At least 6 weeks should be allowed in winter-time for the fumes to clear, remembering that traces of DD are injurious to plants and may cause tainting of fruit. To encourage drying-out, 3 weeks after the application of DD the soil should be dug over roughly, loosening it up without breaking it down. A second digging should follow about 1 week later. Apart from encouraging drying-out, such cultivations diminish the risk of taint. Dung or other organic material may be worked in at this stage. Winter flooding should not be started until all traces of vapour have disappeared, otherwise clearance of DD will be greatly delayed. For the same reason, if formaldehyde is to be used also, it should be applied some weeks before DD treatment, or, if that is impossible, not until all fumes have disappeared after DD treatment. Where steaming and DD are both necessary, steaming should either precede the use of DD by a day or two, or follow it after an interval of at least a month.

DD is a poison and a strong irritant and the precautions recommended by the makers should be followed explicitly.

Ethylene Dibromide

This is another heavy, volatile hydrocarbon. It is non-inflammable, non-corrosive, insoluble in water and without an odour. Ethylene dibromide solutions are not unpleasant to handle but the vapour should not be breathed any more than can be helped. It is probably more toxic to workers than DD. It is dissolved in a suitable, harmless, volatile solvent, usually naphtha (which, by the way, *is* inflammable), the concentration ranging from 5 to 20 per cent by volume in different brands. It is applied with an injector. Residues of ethylene dibromide in the soil are injurious to plants.

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* About 25 to 33⅓ gall./acre.

Ethylene dibromide is effective against root-knot eelworm but not potato eelworm. It is of very little use as a fungicide.

The recommended rate of application for a 10 per cent solution is 2 to 3 ml. at 10 in. centres, equivalent to 30 to 40 gal./acre.

Methyl Bromide

At temperatures above 43° F. methyl bromide is a very active, colourless, odourless gas. For use as a nematocide in U.S.A. it is dissolved in a harmless solvent and sold in sealed cans or steel cylinders as a 10 or 15 per cent solution. It is not yet in use in Britain.

Methyl bromide has excellent penetration properties and is speedy in action. A soil temperature of 60° F. or over is desirable and the soil should be fairly moist. It clears from treated soils in 5 to 7 days after treatment. Indeed, methyl bromide has been used within a foot of growing plants without injury to their roots.

The usual rate of application for 10 to 15 per cent solutions, applied 4 to 5 in. deep, is 5·7 ml. at 10 in. centres.

Because of the speed with which methyl bromide escapes from the soil, it is necessary to tread in the holes and seal the surface at once with water (page 134) to ensure adequate treatment.

Symphalids

Where symphalids are a soil pest it is recommended that plants be watered 2 to 3 days after planting with 0·01 per cent parathion ($\frac{1}{2}$ pt. of a product containing 20 per cent parathion to 100 gal. water), using about 1 pint per plant. *Parathion is highly poisonous to man* and compulsory precautions must be observed whenever and however it is used.

SAFETY PRECAUTIONS

All of the nematocides mentioned in the previous pages contain as their active ingredient some volatile gas that is more or less poisonous. Those with a readily detectable odour give ample warning of their presence. There is little or no warning odour with ethylene dibromide and methyl bromide, hence they should always be handled with plenty of ventilation in the glasshouse. Eyes *must* be protected; soap and water used copiously to rinse the skin; contaminated shoes and clothing immediately removed. If the proper technique is observed and made a habit from the start then 'there seems to be no more danger in handling fumigants than in handling gasoline, explosives or electricity.' It should be noted that rubber boots and gloves afford no protection whatever against methyl bromide.

MECHANIZATION

In U.S.A. large areas of soil, outside as well as inside glasshouses, are treated, using 'power driven, multiple-row, subsurface, continuous-flow injectors. Careful refinement of this fumigation equipment has permitted accurate employment of more and more concentrated fumigants at reduced amounts per acre' (27). It may surprise British readers to learn that probably 200,000 to 300,000 acres of farmland were treated in U.S.A. in 1953.

Mechanization of chemical (or steam) sterilization is almost unheard of in Britain, for the simple reason that there is nothing much to mechanize: we do not use concentrated chemical sterilizers, except in a small way. Even so, it would pay the British grower to keep an eye on his cousin across the water, for the one thing that is certain about chemical sterilizers and fumigants is that we are only at the beginning of their development.

SUMMARY

1. Nematocides are not, strictly speaking, soil sterilizers, but they are often important alternatives to steam and other chemicals for the control of specific pests, viz. nematodes (eelworms).

2. *DD Mixture* is in fairly wide use for glasshouse crops where root-knot eelworm is prevalent. It is injected at 12 to 15 in. centres.

3. *Ethylene dibromide* is a specific for root-knot eelworm. It has been used to a fair extent in U.S.A., but not in Britain.

4. *Methyl bromide* is used in U.S.A., but not in Britain.

5. All of the nematocides are more or less poisonous and must be used with great care.

PART III

CONCLUSION

We have now come to the end of all that need be said in this book about the various methods of using heat and chemicals to sterilize soil.

But we have *not* come to the end of the subject. What happens to soil before and after it is sterilized is an all-important part of successful sterilizing. This is discussed in Chapter 19.

And what happens in the reader's mind is the most important thing of all. Have the principles been grasped? Is the picture clear? Chapter 20 attempts to make it crystal clear—in a Grand Summary.

CHAPTER 19

TREATMENT OF STERILIZED SOIL

Seed and Potting Composts

The selection, preparation and use of loam for seed and potting composts has been fully discussed elsewhere (26). All that need be said here is that if the simple rules and recommendations of the John Innes Horticultural Institution are followed and steam-sterilized loam made into John Innes Compost, then no special treatment of the soil or compost is either desirable or necessary. The composts can be made up as soon as the sterilized loam is cool. They can be used at once. They are completely reliable.

All floors, shovels, wheel-barrows, pots, boxes, etc., involved in the making and use of sterilized soil must be sterilized, using steam or formaldehyde solution, whichever is most appropriate.

Glasshouse Soil

The sterilization of glasshouse soil should not, and cannot, be regarded as an isolated event in glasshouse husbandry. True success in nursery and crop management depends on integrating the best methods at any one time and all the time. Or, to put it another way, to get the best return from sterilizing, attention must be given to requirements that precede the operation as well as those which follow it.

A. *Before Sterilizing*

1. When the glasshouse is cropped until well into winter, leaving little time for soil sterilizing, or when sterilizing must be carried out immediately after a late summer crop, then watering should cease some days before the plants are cleared so that they themselves assist in the drying-out of the soil.
2. In addition to the usual measures taken by way of end-of-crop fumigation, great care should be exercised in the removal of disease- or pest-ridden plants, especially their root systems.

The less trouble left behind in the soil from the last crop, the more likely that a clean start will be made with the next crop.

3. It is customary, and often very necessary, to wash down the glasshouse after a crop has been cleared. This does not matter if soil sterilizing is not to be done for some weeks and the soil has a chance to dry out again. It should not be forgotten, however, that the copious use of water to achieve hygienic conditions in one direction may hinder achievement in another (soil sterilization) if the soil is drenched with water.

4. Conditioning the soil by loosening it up (which will also encourage drying-out) and breaking it down to a good tilth by machine or by hand, *is of the greatest importance*, whether steam or chemicals are to be used.

5. Soil sterilization does not put right conditions which result from careless or ignorant use of fertilizers and manures. Indeed, it may make things worse. Sterilization will yield the largest dividends when the nutrient status of the soil is correct in respect of both concentration and balance of nutrients, and when the physical condition is satisfactory. To reiterate: sterilizing is not a substitute for good soil management but complementary to it.

B. *After Steaming*

1. Every effort should be made to see that sterilized soil is not contaminated (Fig. 34) by walking on it or by dragging tools or plants from dirty soil across it. And all young plants, rooted cuttings, etc., to be planted in the soil should be raised in sterilized soil under fully hygienic conditions.

2. If flooding of the soil in tomato houses is necessary, it should be left until after sterilization. Apart from creating a reserve of water in the subsoil, flooding also washes away the excess soluble salts often found in old glasshouse soils.

It is *impossible* to maintain satisfactory nutrient levels and balance unless soil analyses for nitrogen, phosphate, potash, calcium, etc., are made at regular intervals. A free soil analysis service is provided by the National Agricultural Advisory Service. Alternatively, various analytical chemists will undertake soil analysis at a fee of 2 or 3 guineas. The soil samples are best taken shortly before the crop is to be planted, i.e. after soil sterilization and flooding, but often this is impossible, chiefly because there is not enough time for the analyses to be made in the short interval before planting. The alternative is to take soil samples immediately the crop is finished and, where it applies, let the analyst know that sterilizing and flooding are to be done later. His recommendations can then allow for this. The necessary fertilizers should be applied *after* sterilizing and flooding have taken place. Lime should never be added to soil *before* it is sterilized as it may encourage excess production of ammonia, hence soft, unbalanced plant growth.

If animal manure has never been in contact, off or on the nursery, with pests and diseases that attack the crop, it is better to apply it after the soil has been steamed. The heating of manure encourages the liberation of ammonia and other compounds in excess.

If contamination of the manure is known or suspected, it is far better not to use it at all but, if a soil conditioner is wanted, to turn to *horticultural* peat. Peat does not react to heating in any way inimical to the control of nutrient levels or plant growth and it is sterile. A 1 in. layer of dry peat can be used as an insulating soil-cover during soil steaming and dug in afterwards to improve soil structure (page 24). Probably, it is not advisable to dig in this quantity every year since peat rots slowly and too much may accumulate.

SUMMARY

The sterilization of glasshouse soil is not an isolated event in glasshouse husbandry but must be considered in relation to general nursery management. The clearing of the old crop with its pests and diseases, the drying-out and preparation of the soil, and the correct use of fertilizers, all bear on the success or otherwise of soil sterilization.

CHAPTER 20

SUMMING-UP

In the foregoing pages we have gone into a great many details concerning soil sterilization, including some technicalities we must all be familiar with these days if we are to carry out our job in an intelligent, efficient, and, therefore, profitable manner.

Now, details have their danger for us: we may not be able to see the wood for the trees. So what remains to be done is to gather up these details into one comprehensive picture (Table 14). Of course, one part of the picture may interest us more than the rest, nevertheless, even that part will not reach full significance until we have seen the whole.

It will pay the reader to scan the picture slowly and carefully, first down each column then along each line. Especially should differences between columns be noted and the reason for them called to mind.

Lastly—and most important of all—may I suggest that you use Table 14 to check your own practice? Select the column that concerns you most and, starting at the top, take the successive items one by one, and ask yourself whether you observe them. Where your answer is 'yes,' without qualification, well and good. But if you find yourself hesitating, or if the answer is 'no'—stop. For whether you grow plants for pleasure or profit, it is at that point you have to make up your mind to keep pace with the times—or be left behind.

Table 14

Essentials for Success	Steam			Electricity	Chemical
	Amateur	Commercial			
		Propagation	Glasshouses	Propagation	Commercial Glasshouses
(1) Nature of soil to be sterilized	(*a*) loamy, if possible (*b*) not recently limed or manured	(*a*) medium turf loam (*b*) moderate P & K status (*c*) pH 5·5–6·5 (*d*) standardized in stack	(*a*) good crumb structure (*b*) moderate N, P, K & Ca status (*c*) pH 6·0–6·5	(*a*) medium turf loam (*b*) moderate P & K status (*c*) pH 5·5–6·5 (*d*) commercial: standardized in stack	(*a*) good crumb structure (*b*) moderate N, P, K & Ca status (*c*) pH 6·0–6·5
(2) Condition of soil when ready for sterilizing	(*a*) dry (*b*) sifted, ⅜ in.* (*c*) loose	(*a*) dry (*b*) sifted or shredded, ⅜ in.* (*c*) loose (*d*) not more than 12 in. deep in bin	(*a*) dry (*b*) well broken up by cultivation, < 1½ in.* (*c*) loose	(*a*) sifted or shredded, ⅜ in.* *Electrode* *Immersion* (*b*) firm moderately firm (*c*) saturated potting condition	(*a*) moist (potting condition) (*b*) well broken up by cultivation, < 1½ in.* (*c*) loose
(3) Requirements for efficient sterilizing	(*a*) large area of soil exposed to steam	(*a*) rapid heating (*b*) sterilizing completed by residual heat (*c*) rapid cooling	(*a*) balanced steaming (max. rate steam injection 18 lb./hr/sq. ft.) (*b*) water drained from steam main (*c*) steamed soil covered for further 20 minutes	(*a*) soil temperature at least 180° F. for 10 minutes	(*a*) soil temperature appropriate (*b*) thorough, deep penetration of soil by chemical (*c*) water, or other seal, where necessary (*d*) thorough clearance of fumes
(4) Treatment of soil after sterilizing	(*a*) keep clean (*b*) keep moist	(*a*) keep clean (*b*) keep moist (*c*) keep for not more than 2 months *or* (*c*) make into J. I. Compost (*d*) keep for not more than 2 months	(*a*) keep clean (*b*) flood at once if necessary (*c*) apply fertilizers as indicated by analysis	(*a*) keep clean (*b*) keep moist (*c*) keep for not more than 2 months *or* (*c*) make into J. I. Compost (*d*) keep for not more than 2 months	(*a*) keep clean (*b*) apply fertilizers as indicated by analysis

* Maximum particle size

APPENDIX I

STANDARDIZATION IN SOIL STERILIZATION

IN the context of this book, the ultimate purpose of experimentation and theory is to enable practical decisions to be made.

In theory, a certain size of hole or pipe may be slightly better than any other size. Or a certain distance between steaming pipes, or a certain steam quantity or pressure, or a certain method of working and so on.

In practice, such fine distinctions may be of no consequence, merely confusing and burdensome. Thus, it would be possible to recommend half a dozen different designs of Hoddesdon pipes or combs—with different hole sizes, spacing and position, pipe and spike diameters and lengths—and all of them equally satisfactory. But life is made much simpler for everyone if *one* size of hole, etc., is decided upon; if standardization is introduced for the sake of utility and economy.

The variety of sterilizing appliances and methods used by glasshouse nurserymen is astonishing. We now know it is quite unnecessary.* Standardization is not only possible, on scientific grounds; it is desirable for reasons of economy and to eliminate confusion.

Confusion also prevails because different people use different words to indicate the same thing; or the same word to indicate different things. Hence, standardization of terminology is also desirable. Since only a few words are involved we may as well have common understanding as to their meaning.

The following values and definitions, therefore, are put forward by the author as both adequate and convenient for general use in the practice of soil sterilizing.

---

* The history of seed and potting composts is an exact parallel. Once Everyman made his own composts to his own fancy. Now, not merely as good but better results can be had by every man using the standard John Innes Composts. Standardization in the practice of soil sterilizing is as desirable as standardization in the making of composts. And should be as profitable.

APPENDIX I

TERMINOLOGY

Soil Sterilization. The use of heat or chemicals to bring about the destruction of most or all of those organisms in the soil, including weeds and seeds, directly or indirectly inimical to the health of cultivated plants.

Main. Metal pipe conveying steam from boiler to hoses.

Hose. Flexible metal or rubber pipe conveying steam from main to header or from header to steaming pipes.

Header. Y- or cylinder-shaped pipe unit for distributing steam from one pipe to two or more.

Steaming Pipe. The metal pipe by means of which steam is injected into the soil, e.g. Hoddesdon pipe and the back of a Comb.

Plot. Unit steaming area: the area of bed or bench steamed by one set of Hoddesdon pipes, Combs, Drain Tile, etc.

Bin. Brick, metal or wooden receptacle for holding soil while it is being sterilized.

Trough. Metal container in which water is boiled to make steam in certain bin-sterilizers.

QUANTITIES, APPARATUS, METHODS

STEAM

Quantity. 6 lb. (average) steam/cu. ft. of soil that is dry, loose and in good tilth.

Rate. (i) 18 lb. steam/sq. ft./hr. glasshouse soil that is dry, loose and in good tilth.

equivalent to:

(ii) 3·1 lb. steam/min./7 ft. standard Hoddesdon pipe.

equivalent to:

(iii) 5·6 sq. ft. soil/100 lb. steam/hr.

Pressure. 2 psi/standard Hoddesdon pipe.

STEAMING PIPES

(i) *Hoddesdon*

Pipe: 1¼ in. internal diameter, plugged at distant end, with an inverted L-shaped 'riser' at near end.

Holes: ⅛ in. diameter, spaced 5 in. apart in two staggered rows, one on each side of the pipe.

(ii) *Comb*

Pipe: 1¼ in. internal diameter.
Spikes: 15 in. long, ⅜ in. internal diameter, spaced 12 in. apart along pipe.
Holes: four, ⅛ in. diameter, equally spaced around circumference of spike, about 1 in. from pointed end.

Spacing and Depth (for general purposes)
(i) Hoddesdon: 18 in. apart, 12 in. deep.
(ii) Comb: 18 in. apart.

Plot Size per Boiler Output

For every 100 lb. steam/hr. boiler output:
Plot size = 5·6 sq. ft.
Steaming pipe length = 3·75 ft.
e.g. for 1,000 lb. boiler:
Plot size = 56 sq. ft.
Steaming pipe length = 37·5 ft.

BIN STERILIZERS

(i) *General*

Capacity	Length	Breadth	Depth
1 cu. yd.	5 ft. 3 in.	5 ft. 3 in.	1 ft.
½ cu. yd.	3 ft. 8 in.	3 ft. 8 in.	1 ft.
¼ cu. yd.	2 ft. 8 in.	2 ft. 8 in.	1 ft.

(ii) *John Innes High-Rate Sterilizer*

Bin, 12 in. deep			Internal diameter of headers	
Capacity cu. yd	Internal dimension	Number of grid pipes	Front (steam)	Back (condensate)
1	5 ft. 3 in. sq.	7	2 in.	1½ in.
½	3 ft. 8 in. sq.	5	1¼ in.	1 in.
¼	2 ft. 8 in. sq.	4	1 in.	¾ in.

Steaming Time: not more than 15 minutes' actual steaming.

APPENDIX II

USEFUL FIGURES

LENGTH

12 inches (in.)	1 foot (ft.)
3 ft.	1 yard (yd.)
1 in.	2·54 centimetres (cm.)
1 ft.	30·48 cm.
1 yd.	91·44 cm.
Circumference of circle	3·1416 × diameter

AREA

144 square in. (sq. in.)	1 sq. ft.
9 sq. ft.	1 sq. yd.
4,840 sq. yd.	1 acre
43,560 sq. ft.	
1 sq in.	6·4516 sq. cm.
1 sq. ft.	929·03 sq. cm.
1 sq. yd.	8,361·26 sq. cm.
1 acre	0·4047 hectare
Area of circle	3·1416 × radius squared

VOLUME

(i) 1,728 cubic in. (cu. in.)	1 cu. ft.
27 cu. ft.	1 cu. yd.
1 cu. in.	16·3872 cu. cm. (c.c.)
1 cu. ft.	0·028317 cu. metre
1 cu. yd.	0·764553 cu. metre

(ii)	2 pints (pt.)	1 quart (qt.)
	4 qt.	1 Imperial gallon (gall.)
	8 gall.	1 bushel (bush.)
	21·028 bush.	1 cu. yd.
	1 pt.	0·568 litre (l.)
	1 gall.	4·546 l.
	1 bush.	36·368 l.
(iii)	1 cu. ft.	6·229 imp. gall. 7·481 U.S.A. gall. 0·779 bush.
	1 cu. yd.	168·17 gall.
	1 imp. gall.	277·274 cu. in. 0·161 cu. ft. 1·201 U.S.A. gall.
	1 bush.	2,219·3 cu. in. 1·284 cu. ft.

WEIGHT

16 ounces (oz.) avoirdupois	1 pound (lb.)
14 lb.	1 stone (st.)
28 lb.	1 quarter (qr.)
112 lb. 4 qr.	1 hundredweight (cwt.)
2,240 lb. 20 cwt.	1 ton
1 ton	1·120 U.S.A. ton
1 oz.	28·3495 grams (gm.)
1 lb.	0·4536 kg.

PRESSURE

1 atmosphere	14·696 lb./sq. in. 1·033 kg./sq. cm.
1 lb./sq. in.	0·0703 kg./sq. cm. 0·0680 atmos.

APPENDIX II

TEMPERATURE

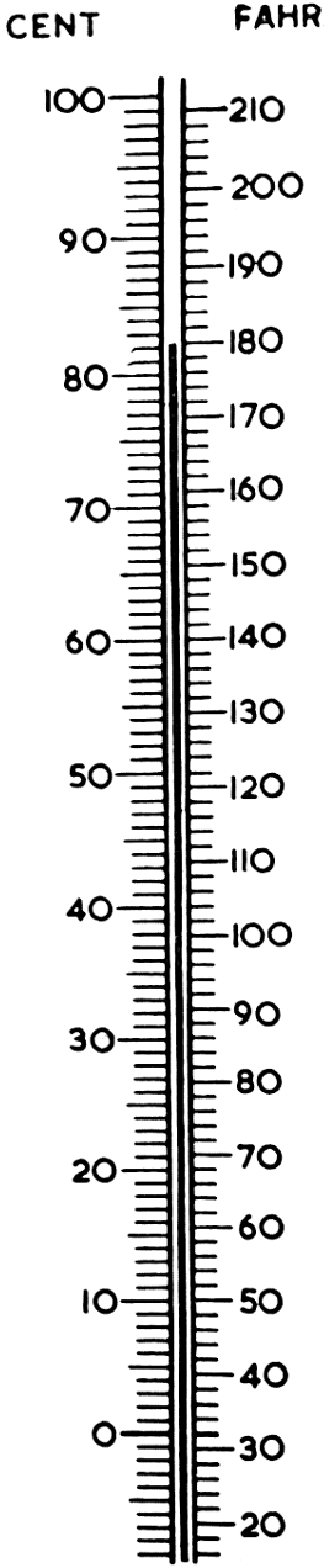

FIG. 35.—Fahrenheit–Centigrade Conversion Scale.

To convert: (i) Degrees Fahrenheit to Centigrade: $°C. = (°F. - 32) \times \frac{5}{9}$.
(ii) Degrees Centigrade to Fahrenheit: $°F. = (°C. \times \frac{9}{5}) + 32$.

POWER

1 mechanical horse power (h.p.)	2,545 Btu/hr.
1 boiler h.p.	33,479 Btu/hr., or the evaporation of 34·5 lb. water/hr. from and at 212° F.

ENERGY CONVERSION

Table 15

(i)

Unit	Btu/hr.	Watt/hr.	H.P./hr.
1 Btu/hr.	1	0·2928	0·000393
1 Kilowatt/hour	3,413	1,000	1·3410
1 mechanical horse power/hr.	2,545	745·7	1
1 boiler horse power/hr.	33,479	—	—

(ii)

Unit	Btu	Watt	H.P.
1 lb. coal (average)	12,000	3,516	0·4715
1 lb. fuel oil	18,900 (gross)	5,534	0·7428
1 gall. fuel oil	175,770	51,466	6·9080

WATER

(i) density = 1·0 at 4° C.
(ii) specific heat = 1·0 at 20° C.
(iii) volume/weight
1 gall. = 10 lb.
1 lb. = 0·10 gall.
1 cu. ft. = 62·288 lb.
1 lb. = $\begin{cases} 0\cdot016 \text{ cu. ft.} \\ 0\cdot455 \text{ l.} \end{cases}$
(iv) 1 litre = 1,000·027 c.c. } at 4° C. and 760 mm. pressure.
1,000 c.c. = 999·973 l. }
1 millilitre (ml.) = $\begin{cases} 0\cdot001 \text{ l.} \\ 1 \text{ c.c. (approx.)} \end{cases}$

(v)

Table 16

APPROXIMATE AMOUNTS OF WATER REQUIRED TO STEAM STERILIZE DRY, MEDIUM LOAM* (BASED ON 6 LB. WATER/CU. FT. SOIL†)

Amount of soil	Amount of water
3 pints	¼ pint
6 pints	½ pint
1 gall.	¾ pint
2 gall.	1½ pints
4 gall.	3 pints
6 gall.	4½ pints
1 bush.	6 pints
2 bush.	1½ galls.
¼ cu. yd.	4 galls.
½ cu. yd.	8 galls.
1 cu. yd.	16 galls.

* i.e., dry to the touch or, say, 15–20 per cent moisture content.

† i.e., the approximate water requirement under average working conditions.

STEAM

(i) Specific heat = 0·5.

(ii) Temperature

Table 17

THE RELATION OF STEAM TEMPERATURE TO STEAM PRESSURE AND VOLUME

Pressure psi (gauge)	Temperature: °F.	Volume cu. ft./lb.
0	212	26·8
10	239	16·5
15	250	13·9
20	259	12·0
25	267	10·6
30	274	9·5
40	287	7·8
60	307	5·8
80	324	4·7
100	338	3·9

(iii) Flow through holes in pipes (cf. Hoddesdon pipe). The rate of flow of dry saturated steam in lb./min. = $5{\cdot}2A\sqrt{P}$, where A = total hole area in sq. in. and P = gauge pressure in pipe in psi.

(iv) Pipes

Table 18

PIPE DIMENSIONS

Nominal bore, in.	External diameter, in.	Surface, sq. ft. per foot	Sectional area, in.
$\frac{1}{8}$	—	—	0·01225
$\frac{1}{4}$	$\frac{17}{32}$	0·14	0·049
$\frac{3}{8}$	$\frac{11}{16}$	0·11	0·110
$\frac{1}{2}$	$\frac{27}{32}$	0·22	0·196
$\frac{3}{4}$	$1\frac{1}{16}$	0·28	0·442
1	$1\frac{11}{32}$	0·35	0·785
$1\frac{1}{4}$	$1\frac{11}{16}$	0·44	1·227
$1\frac{1}{2}$	$1\frac{29}{32}$	0·50	1·767
2	$2\frac{3}{8}$	0·62	3·142
$2\frac{1}{2}$	3	0·79	4·909
3	$3\frac{1}{2}$	0·92	7·069

(v) Steaming Rate

From experiments (9), a rate of 18 lb. steam/hr./sq. ft. glasshouse soil surface has been selected as the maximum for combining thermal efficiency with convenience of working. Injection is efficient at all rates up to 18 lb./hr/sq. ft. soil, but rates much lower than this are unacceptable in practice since the size of the plot would then be too large. At a higher rate than about 18 lb./hr./sq. ft. soil, some of the steam will not condense and will be wasted.

SOIL

A = light sandy soil (lower greensand).
B = heavy soil (gault clay).

(i) Specific heat $\left.\begin{array}{l}A = 0{\cdot}192\\ B = 0{\cdot}202\end{array}\right\}$ oven dry condition.

(ii) heat capacity A = 24 Btu/cu. ft./°F. with 9 per cent moisture content.
B = 53 Btu/cu. ft./°F. with 58 per cent moisture content.

(iii) Moisture capacity range
A = dry 9 per cent; saturated and drained 26 per cent.
B = dry 19 per cent; saturated and drained 58 per cent.

(iv) Volume/weight (approximate)
1 cu. ft. dry, loose loam = 50 lb.
1 bush. dry, loose loam = 65 lb.

(v)

Table 19

AMOUNT OF LOAM REQUIRED TO MAKE JOHN INNES SEED AND POTTING COMPOSTS

Desired amount of compost	Amount of loam required	
	JIS	JIP
1 gall.	*2 pints*	5 pints
1 bush.	*2 galls.*	5 galls.
¼ cu. yd.	1¼ bush.	3 bush.
½ cu. yd.	2½ bush.	6 bush.
1 cu. yd.	*5¼ bush.*	*12¼ bush.*

Italic type = exact amount.
Other figures approximate amount.

FUEL

Table 20

(i) TYPICAL HEAT CONTENTS (BTU) OF FUELS

Material	Btu
1 lb. anthracite	14,500
1 lb. Welsh steam coal	13,500–14,000
1 lb. Midland steam coal	11,000–12,000
1 lb. Midland washed singles	11,000–12,000
1 lb. furnace coke	12,000
1 lb. gas coke	11,500
1 lb. coke breeze	8,000–10,000
1 lb. fuel oil	18,900 (gross)
1 kw electricity	3,413

(ii) FUEL OIL CONVERSIONS (SPECIFIC GRAVITY 0·93)

1 lb. = 1·075 gall.
1 gall. = 9·3 lb.
1 ton = 241 gall.

PUBLICATIONS FOR REFERENCE

(1) NEWHALL, A. G. (1940): *Experiments with New Electric Devices for Pasteurizing Soils.* Cornell University Agricultural Experiment Station, U.S.A., Bulletin 731.

(2) SHEARD, G. F.: *An Investigation of the Partial Sterilization of Soil for Horticultural Purposes with Special Reference to the Use of Electrical Equipment* (unpublished thesis).

(3) KIDSON, E. B. (1948): *The Effect of Steam and Chloropicrin Treatment on theAmmonia and Nitrate Nitrogen Content of a Nelson Tomato Soil.* New Zealand Journal of Science and Technology, No. 30, pp. 193–9.

(4) DAVIES, J. N., and OWEN, O. (1951): *Soil Sterilization:* I. *Ammonia and Nitrate Production in Some Glasshouse Soils following Steam Sterilization.* Journal of the Science of Food and Agriculture, No. 2, pp. 268–79.

(5) WALKER, T. W., and THOMPSON, R. (1949): *Some Observations on the Chemical Changes Effected by the Steam Sterilizing of Glasshouse Soils.* Journal of Horticultural Science, No. 25, pp. 19–35.

(6) ROLL-HANSEN, J. (1952): *Damping av jord til tomat* (*Steaming of Soil for Tomatoes*). State Experiment Station, Kvithamar, Report No. 10, pp. 229–59.

(7) FUJIMOTS, C. K., and SHERMAN, G. D. (1948): *Manganese Availability as Influenced by Steam Sterilization of Soils.* Journal of the American Society of Agronomy. No. 40, pp. 527–34.

(8) RUSSELL, E. J., and PETHYBRIDGE, F. R. (1912): *Partial Sterilization of Soil for Glasshouse Work.* Journal of the Board of Agriculture, Vol. 18, No. 10.

(9) BUNT, A. C. (1955): *Steam Pressure in Soil Sterilization:* II. *Glasshouse* in situ *Sterilizing.* Journal of Horticultural Science, Vol. 30, pp. 43–55.

(10) BUNT, A. C.: *Annual Report for 1954.* John Innes Horticultural Institution.

(11) MINISTRY OF FUEL AND POWER (1943): *Steam for Process and Heating*. Fuel Efficiency Bulletin, No. 25. Price 9d.

(12) MORRIS, L. G. (1952): *The Steam Sterilizing of Soil: Experiments on Fine Soil.* National Institute of Agricultural Engineering, Report No. 14.

(13) MORRIS, L. G., and WINSPEAR, K. W. (1954): *The Steam Sterilizing of Lumps of Soil.* National Institute of Agricultural Engineering, Technical Memorandum No. 113.

(14) MORRIS, L. G. (1954): *The Steam Sterilising of Soil: the Application of Research to Practice.* National Institute of Agricultural Engineering, Report No. 24.

(15) BUNT, A. C. (1954): *Steam Pressure in Soil Sterilization: I. In Bins.* Journal of Horticultural Science, No. 29, pp. 89–97.

(16) MINISTRY OF FUEL AND POWER (1945): *Water Treatment.* Fuel Efficiency Bulletin, No. 39. Price 4d.

(17) MINISTRY OF FUEL AND POWER (1945): *The Stoker's Manual.* Price 1s. 6d.

(18) SENNER, A. H. (1934): *Application of Steam in Sterilization of Soils.* United States Department of Agriculture, Technical Bulletin 443.

(19) DIMOCK, A. W., and POST, K. (1944): *An Efficient, Labor-Saving Method of Steaming Soil.* New York State College of Agriculture, Bulletin 635.

(20) LAWRENCE, W. J. C. (1950): *Science and the Glasshouse.* Oliver & Boyd, Edinburgh. Price 15s.

(21) BROWN, C. A. C., and WAKEFORD, P. (1947): *Electrical Soil Sterilization by Immersion Heaters.* Electrical Research Association, Technical Report W/T14.

(22) CANHAM, A. E. (1951): *Electrode Soil Sterilizing.* Electrical Research Association, Technical Report W/T21.

(23) GOLDING, E. W. (1953): *The Use of Electricity to Increase Soil Temperature.* Electrical Research Association, Technical Report W/T26.

(24) NEWHALL, A. G. (1946): *Volatile Soil Fumigants for Plant Disease Control.* Soil Science, No. 61, pp. 67–82.

(25) NEWHALL, A. G., and LEAR, B. (1948): *Soil Fumigation for Nematode and Disease Control.* Cornell University Agricultural Experiment Station, U.S.A., Bulletin 850.

(26) LAWRENCE, W. J. C., and NEWELL, J. (1952): *Seed and Potting Composts.* Allen & Unwin, London, Price 8s. 6d.

(27) NEWHALL, A. G. (1955): *Disinfestation of Soils by Heat, Flooding and Fumigation.* Botanical Review, No. 21, pp. 189–250.

(28) FAIRFIELD HORTICULTURAL EXPERIMENTAL STATION: Unpublished results.

COMMONWEALTH BUREAU OF SOIL SCIENCE (1948): *Soils and Fertilizers,* No. 11, pp. 357–60. A review.

JOHNSON, J. (1946): *Soil Steaming for Disease Control.* Soil Science, No. 61, pp. 83–91. A review.

PRACTICAL SOIL STERILIZATION WITH SPECIAL REFERENCE TO GLASSHOUSE CROPS (1947): Bulletin No. 22, Ministry of Agriculture, London.

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- No canvas soil container that will quickly rot.

Below are two of the numerous testimonials we have received.

The Hollies,
Wyaston,
Ashbourne, Derby.

Dear Sirs,

The 1-Bushel Model Steam Steriliser which you supplied me with recently has certainly proved to be an asset to horticulture.

I used this model outside, averaging 16 hours' work each day for a fortnight, sterilising many mixtures and types of soils.

In every case it was 100 per cent efficient; on an open fire we completed two operations per hour and in each case the temperature was 210–212 degrees Fahrenheit.

This was certainly a severe test. All I can say is, this Steriliser is the most efficient, economical and satisfactory purchase I have ever made in horticultural equipment.

Great credit is due to the design and manufacture.

Many thanks, Yours sincerely,
G. R. KENT.

Hawkhead Road Nursery,
Hawkhead Road, Paisley.

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I purchased one two years ago and have sterilised enough soil for approximately 800 boxes and find no wear on it.

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(*Signed*) George D. SIMPSON.

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